# GROUND WATER IN THE NIAGARA FALLS AREA, NEW YORK

## With Emphasis on the Water-Bearing Characteristics of the Bedrock

BY

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# CONTENTS



Front cover--View of the east wall of New York State Power Authority conduit No. 1 in January 1959. Seepage from bedding joints in the Lockport Dolomite forms frozen cascades on the rock face. (Photograph by the Power Authority of the State of New York.)

# CONTENTS (Continued)

# ILLUSTRATIONS

# ILLUSTRATIONS (Continued)

# TABLES

# GROUND WATER IN THE NIAGARA FALLS AREA, NEW YORK

## With Emphasis on the Water-Bearing Characteristics of the Bedrock

By
Richard H. Johnston

## ... ABSTRACT

The Niagara Falls area encompasses 550 square miles in the extreme northwestern corner of New York. The area is one of very low relief except for the Niagara escarpment and the gorge of the Niagara River. A thin cover of Pleistocene unconsolidated deposits overlies the bedrock throughout most of the area. These deposits consist of three types: (1) glacial till, (2) lake deposits, and (3) a few small sand and gravel deposits. The bedrock consists of nearly flat-lying sedimentary rocks of Paleozoic age. The southern one-third of the area is underlain by the Lockport Dolomite (Silurian) and the northern two-thirds of the area by the Queenston Shale (Ordovician). Between these is a small area along the gorge and escarpment which is underlain by a series of thin limestones, shales, and sandstones.

The Lockport Dolomite is the only important aquifer in the Niagara Falls area. Ground water occurs in it in three types of openings: (1) bedding joints which constitute at least seven important water-bearing zones, (2) vertical joints, and (3) small cavities from which gypsum has been dissolved. Of these, the bedding joints are the most important and transmit nearly all the water moving through the formation. The character of the three types of water-bearing openings results in two distinct sets of ground-water conditions: (1) a moderately permeable zone at the top of rock, generally 10 to 15 feet thick, characterized by both vertical joints and bedding joints that have been widened by solution of dolomite and by small cavities formed by solution of gypsum, and (2) the remainder of the formation consisting of seven permeable zones (composed of bedding joints) surrounded by essentially impermeable rock. In the upper part of rock, either artesian or water-table conditions may exist locally. However, in the lower part of rock, the seven water-bearing zones act as separate and distinct artesian aquifers. Recharge to the water-bearing zones apparently occurs directly at the outcrop of the bedding joints composing the zones rather than by downward movement of water through vertical joints. Ground water in the Lockport, characteristically a calcium sulfate or calcium bicarbonate water, is very hard and moderately mineralized. A highly mineralized water, characterized by higher concentrations of sodium and chloride than those measured in typical Lockport water, occurs in the lowest two zones of the formation.

The chief use of ground water in the Niagara Falls area is for small domestic and farm supplies in the rural sections. Small to moderate supplies of ground water (5 to 150 gallons per minute) may be obtained throughout the area underlain by the Lockport Dolomite. Large supplies of ground water (exceeding 2,000 gallons per minute in some wells) have been obtained from the Lockport within a small area adjacent to the Niagara River where conditions are favorable for river infiltration. Throughout the remainder of the area, which is underlain mostly by the Queenston Shale, the development of even the very small supplies needed for domestic and farm use is difficult.

Data tabulated in this report include 316 well and spring records, graphical logs of 58 wells and test borings, and chemical analyses of 83 ground-water samples.

# ... INTRODUCTION

## PURPOSE AND SCOPE

This report presents the results of an investigation of ground water in the Niagara Falls area of New York. The purposes of the investigation were to describe: (1) the occurrence, availability, and quality of ground water in the area, and (2) the geologic framework and hydrologic conditions which control the occurrence and availability of ground water. Although the Niagara Falls area is one of the most water-abundant parts of the nation, situated as it is adjacent to the Niagara River and Lake Ontario, the development of ground-water supplies by some industries and many rural households has been and will continue to be important because of its ready availability in areas remote from the river and lake. The study is one of a series of ground-water investigations made by the U.S. Geological Survey in cooperation with the New York Water Resources Commission (successor to the New York Water Power and Control Commission). Figure shows the current status of ground-water investigations in the State. The area covered by this report is shown in black; areas covered by previous published reports and areas currently under investigation are shown by other patterns.

Some 36,000 people in the rural parts of the Niagara Falls area depend on small supplies of water from privately owned wells for domestic and farming needs. Except in times of drought, these supplies are usually adequate for the modest rural needs. The development of large supplies of ground water, on the other hand, is very difficult in the Niagara Falls area. Elsewhere in New York, large supplies of ground water are developed mostly in sand and gravel deposits filling stream valleys. Such coarse-grained stratified deposits are too thin and limited in areal extent to yield large supplies in the Niagara Falls area. The only important aquifer in the area is the Lockport Dolomite, but it generally yields only small to moderate supplies of ground water, and in places yields water of poor quality. Because the Lockport is the only important source of ground water, special emphasis was placed on a study of its water-bearing characteristics. It is hoped that the results of this study may also contribute to knowledge of the occurrence of ground water in bedrock generally.

Data in this report were collected during the field seasons of 1960, 1961, and 1962. This work included: (1) collecting records of wells, springs, and test borings, (2) study of rock outcrops and excavations, (3) periodic water-level measurements in numerous observation wells, (4) operating recording gages on a few selected observation wells, (5) conducting pumping tests, and (6) collecting water samples for chemical analyses. Tables in the report include records of 298 wells and 18 springs, graphical logs for 58 wells and test borings, and chemical analyses of 83 ground-water samples.

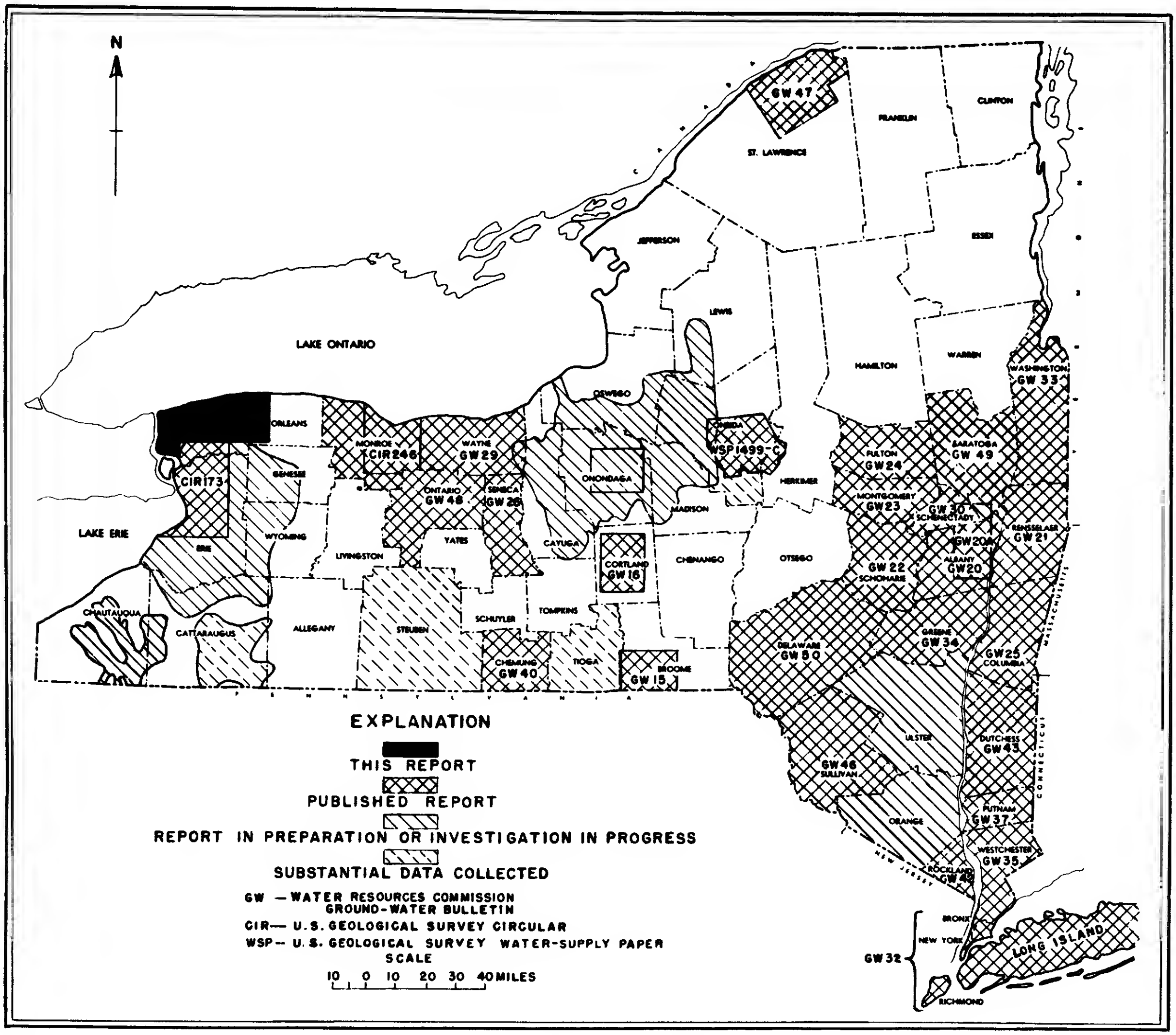



Figure 1.--Index map of New York showing location of the Niagara Falls area and the status of ground-water investigations.

The field work and preparation of the report were under the direct supervision of Ralph C. Heath, District Geologist of the Ground Water Branch, U.S. Geological Survey.

## LOCATION OF AREA

The area described in this report is in the extreme northwest corner of New York. Figure 2 shows the boundaries of the area and the principal places and physical features. It includes the area drained by the Niagara River and Lake Ontario, from Cayuga Creek at Niagara Falls to Oak Orchard Creek at Medina. The area, approximately 550 square miles, includes most of Niagara County plus the western quarter of Orleans County.

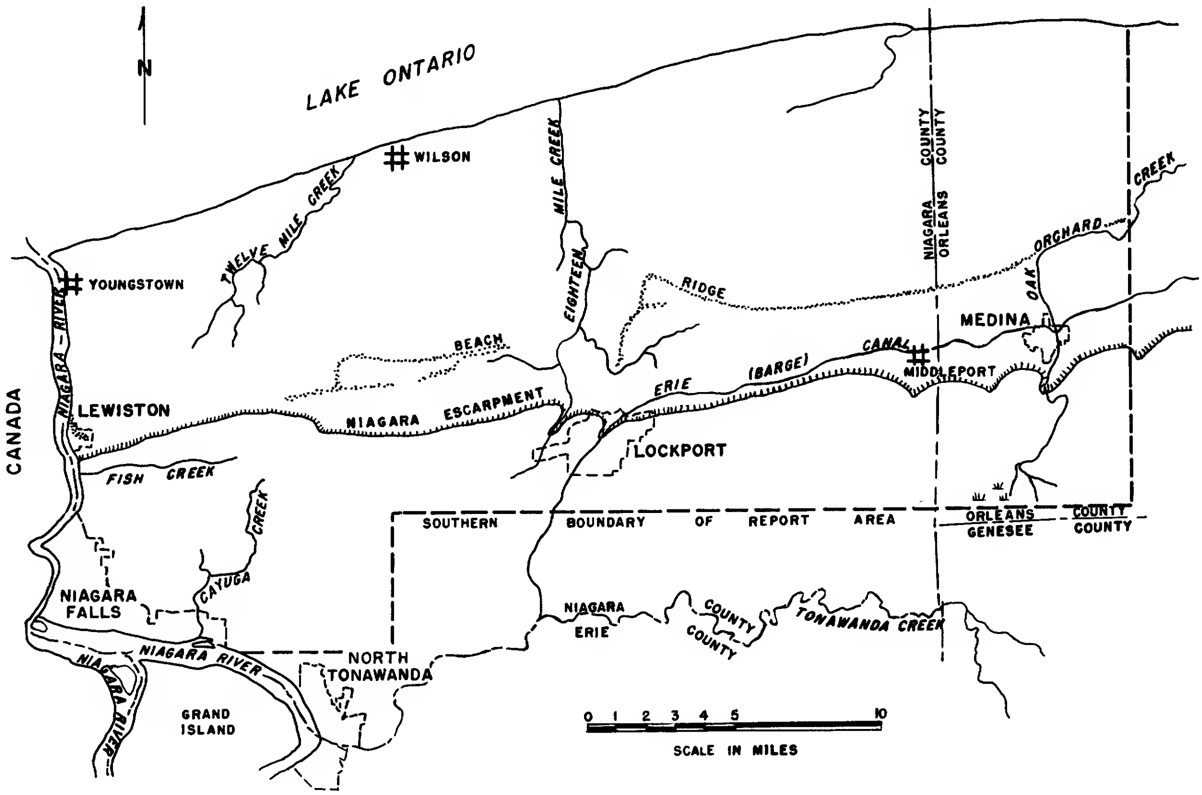



Figure 2.--Physical features of the Niagara Falls area.

The population of the area is about 216,000 persons. Cities and incorporated villages and their 1960 population from the U.S. Bureau of the Census are listed below:

| | | |
|---|---|---|
| NIAGARA COUNTY | Lewiston | 3,320 |
| | Lockport | 26,443 |
| | Middleport | 1,882 |
| | Niagara Falls | 102,394 |
| | Wilson | 1,320 |
| | Youngstown | 1,848 |
| ORLEANS COUNTY | Medina | 6,681 |

## NIAGARA POWER PROJECT

The Niagara Power Project, the largest hydroelectric development in the United States, was under construction during the field investigation of this study. This project, which was built by the Power Authority of the State of New York during the period 1958-62, takes advantage for power generation of the relatively constant discharge of the Niagara River and the drop in head at Niagara Falls. The principal features of the project are shown in figure 3.

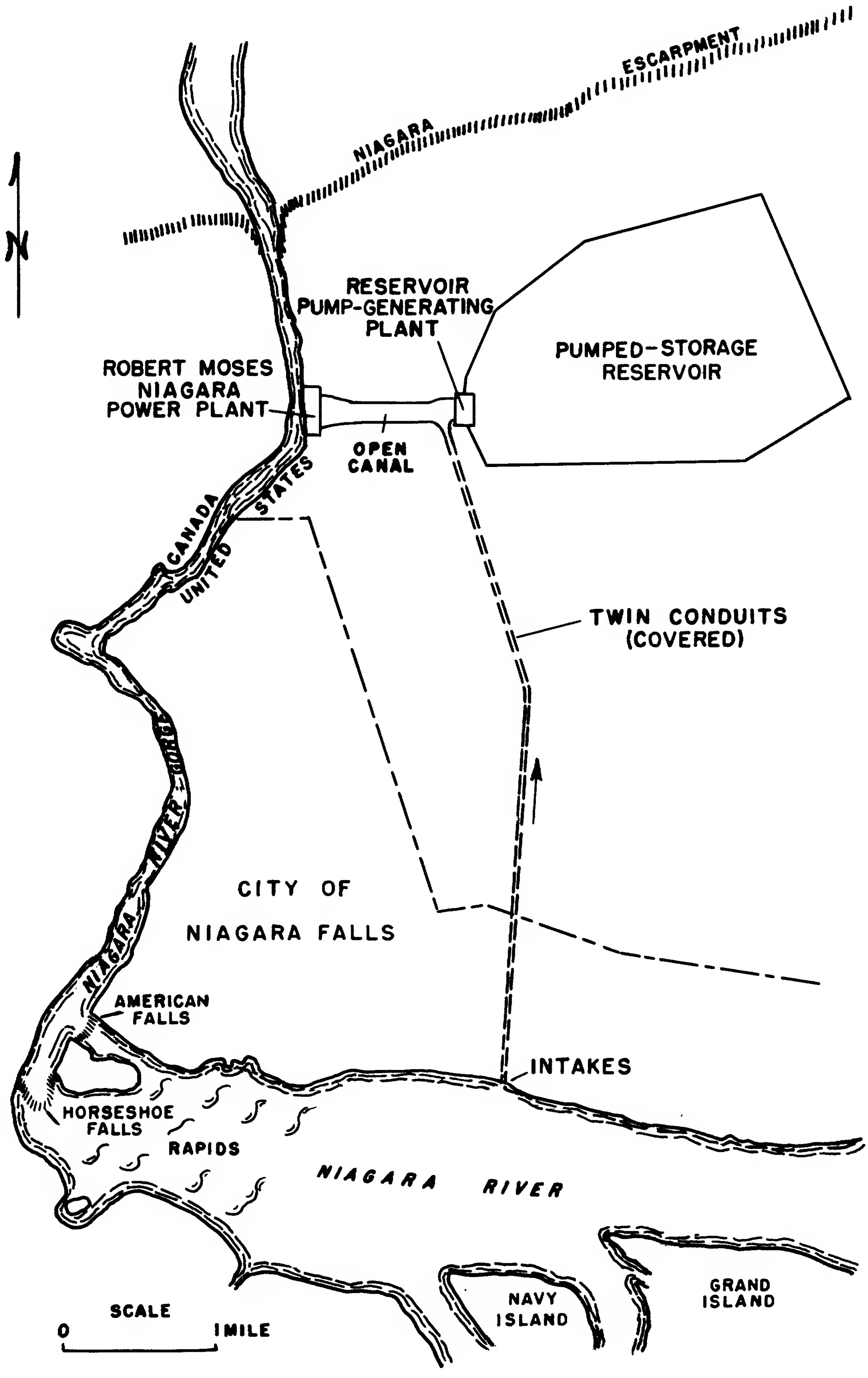



Figure 3.--Features of the Niagara Power Project.

Excavations made during construction of the project provided the writer with excellent opportunities to investigate the water-bearing characteristics of bedrock in the area. The generation of power, which was underway during the latter phases of the field work, also provided opportunities for certain hydrologic observations. Because various features of the power project will be discussed in the following sections, it appears desirable to describe briefly the major features of the project at this point.

Water is diverted from the Niagara River at a point 3 miles above the falls and passes through twin buried conduits to an open canal above the Robert Moses Niagara Power Plant. The water drops an average of 325 feet passing through the main generating plant to the lower river. This 325-foot drop in head between the upper and lower river includes the impressive 160-foot drop at the falls, 50 feet in the rapids above the falls and 115 feet in the Niagara River gorge. A pumped-storage reservoir is used to store surplus water not needed for power generation during periods of low power demand. The water is usually pumped into the reservoir at night or on weekends and is withdrawn during week days.

The average discharge of the Niagara River, as measured at Buffalo, is 203,000 cfs (cubic feet per second), the minimum is 100,000 cfs, and the maximum is 274,000 cfs (U.S. Geol. Survey, 1961, p. 221). Compared to most other streams this is a relatively small fluctuation of discharge and makes the Niagara River one of the world's most dependable sources of hydro-electric power. Water is diverted from the river for generating power under the terms of a treaty signed by the United States and Canada in 1950. This treaty provides that at least 100,000 cfs must flow over Niagara Falls during daylight hours of the tourist season (April 1 to October 31) to maintain the scenic beauty of the falls. During the period from November through March a flow of no less than 50,000 cfs must be maintained. All water above these amounts may be diverted for power generation and is equally divided between the United States and Canada for this purpose.

## ACKNOWLEDGMENTS

Many individuals, companies, and government agencies provided assistance during the course of the study. The writer is particularly indebted to Mr. William H. Latham, resident engineer of the Power Authority of the State of New York, for allowing him access to the excavations of the Power Project and for permitting publication of data collected at the project.

Uhl, Hall & Rich, engineers for the Power Authority, provided invaluable assistance. Members of the Geology and Soil Sections of Uhl, Hall & Rich maintained recording gages on wells, and assisted during pumping tests and other field work. Thanks are due Messrs. C. T. Douglas, Charles Benziger, and Donald Houghton for arranging this assistance. The writer especially wants to thank Mr. Benziger, head of the Geology Section, who assisted in many ways and gave liberally of his time to discuss the geology and ground-water conditions in the area. Other members of the Geology Section who helped in the field included William Santamour, Kernan Davis, and David Brown.

Drilling contractors who provided information on wells include: William Buetel and Sons, Sanborn, N. Y.; Layne-New York Co., Inc., Pittsburgh, Pa.; William Strausberg and Sons, Pekin, N. Y.; and Marvin Wendt, Sanborn, N. Y. The following agencies provided logs of test holes: The New York State Dept. of Public Works, the U.S. Army Corps of Engineers, and the city of Niagara Falls. Mr. Leon Wendell, consultant to the Niagara County Water District and Planning Board, provided information on wells and public water systems. Many individual well owners permitted access to their property and supplied information on their wells.

## PREVIOUS INVESTIGATIONS

The geology of the Niagara Falls area has been described in many reports beginning with the early surveys of New York. James Hall (1843) first discussed the area in his report on the Fourth District. The geomorphic history and development of Niagara Falls are described in the classic monograph by Gilbert (1895). Grabau (1901) described in detail the Paleozoic rocks and fossils of the Niagara Falls area. The Niagara Folio by Kindle and Taylor (1913) describes both the Paleozoic rocks and the unconsolidated deposits, and includes a detailed glacial history of the area. Recent reports by Cannon (1955) and Bolton (1957) cover special aspects of the geology of the area.

Knowledge of the geology of the Niagara Falls area was further extended by studies made prior to and during construction of the Niagara Power Project. Preliminary studies of the bedrock were made in 1951 and 1953 by C. W. Rose for the Corps of Engineers. During construction of the power project, Uhl, Hall & Rich, engineers for the Power Authority, carried out intensive studies of both bedrock and unconsolidated deposits. The results of these studies are not available in published form but were available to the author for consultation.

The water resources of the Buffalo-Niagara Falls region are summarized in a report by Reck and Simmons (1952). This publication describes the availability of both surface- and ground-water supplies, with emphasis on the development of large supplies for industry and municipalities.

## WELL-NUMBERING SYSTEM

The wells, springs, and sites of geologic information described in this report are numbered on the basis of a geographic-grid system based on latitude and longitude. The Niagara Falls area lies between latitude 43° and 44° N. and between longitude 78° and 79°30' W. The area has been divided into quadrangles of 1 minute of latitude and longitude on a side. Each well number consists of three parts: first, the digits of latitude, such as 310 for 4<u>3</u>°<u>10</u>' (omitting the number "4"); second, the digits of longitude, such as 859 for 7<u>8</u>°<u>59</u>' (omitting the number "7"); and third, the number assigned to the well within the 1-minute quadrangle. The complete well number of the first well listed within the 1-minute quadrangle described above would be 310-859-1. Figure 4 illustrates this numbering system.

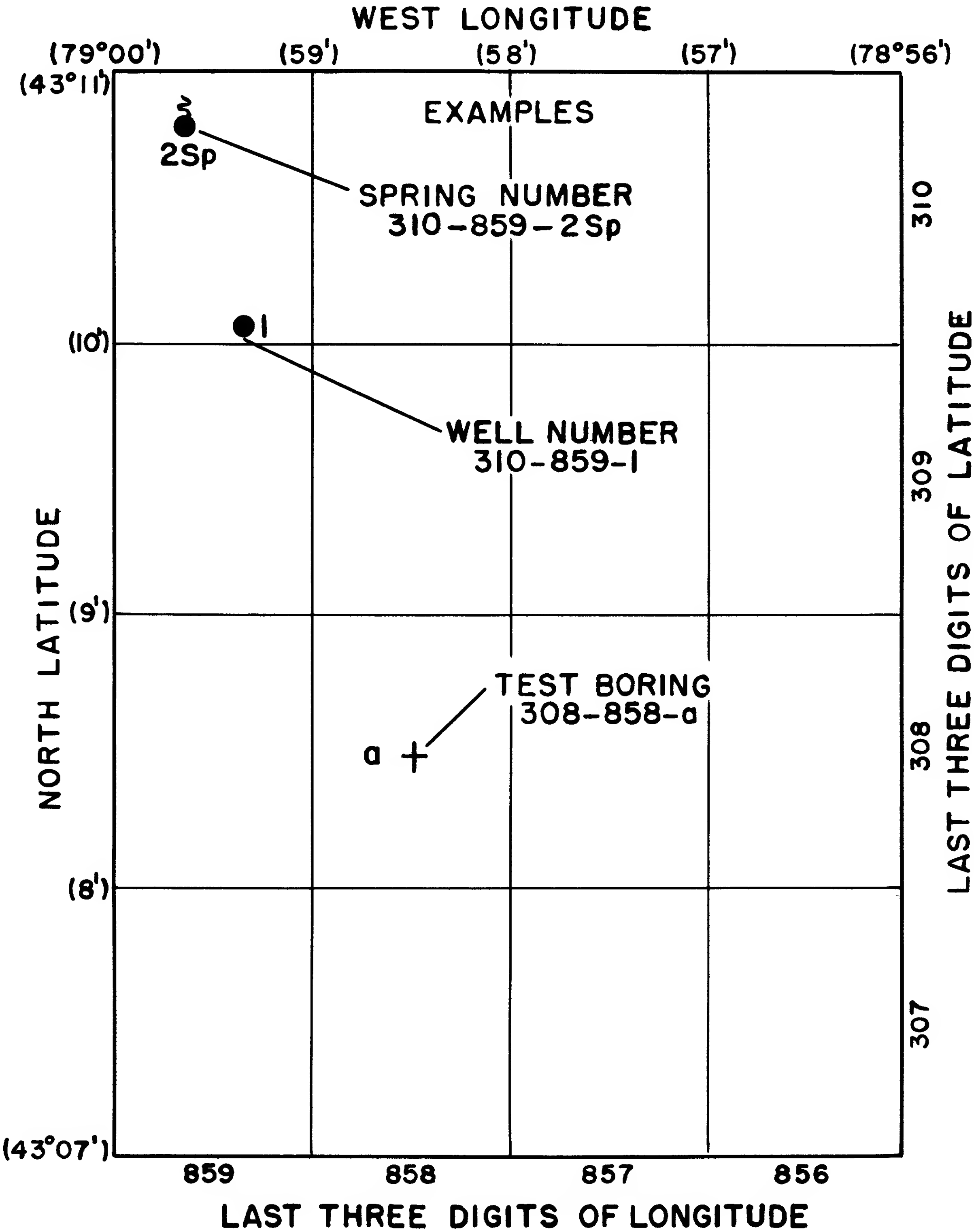



Figure 4.--Well-numbering system.

A spring number is the same as a well number, except that the suffix "Sp" is added, such as 310-859-2Sp. A test boring or other site of geologic information is identified by a small letter instead of a number, such as 308-858-a (fig. 4).

On well-location maps in this report (pls. 1 and 3), the first two parts of each site number (last three digits of latitude and of longitude) are shown along the margin of the maps and only the number of the site within each 1-minute quadrangle is shown with the appropriate well, spring, or geologic site symbol (fig. 4).

Prior to 1957 the well-numbering system in use in New York State consisted of a county letter-symbol, such as "Ni" for Niagara, followed by a number which was assigned in consecutive order as the well inventory was being made. Thus, the well now assigned number 312-859-1, was formerly well number Ni 5.

# . . . SIMPLIFIED METHOD FOR USING THIS REPORT

For the user of this report who is primarily interested in determining the availability of ground water in a particular part of the area, the suggestions below may save time in locating the desired information. Several maps and tables were designed to help readers seeking information on the regional occurrence of ground water.

The map showing the availability of ground water and locations of wells (pl. 3) should be examined first. From this map the reader may determine the principal water-bearing unit in the area of his interest. Note that most of the units are bedrock--dolomite, limestone, sandstone, or shale. The explanation on the map describes the average yield of wells and chemical quality of the ground water in each of the principal water-bearing units. Data on the yield of many individual wells are shown adjacent to the well symbols on the map. Salty or sulfurous wells are identified, respectively, by horizontal or vertical lines drawn through the well symbol. If the reader is interested in the area close to the city of Niagara Falls, he should refer to the large-scale map in plate 2.

For additional information on individual wells, the reader should note the well number and refer to that number in table 7, which contains data on the construction, yield, depth, depth to water level, etc. If "log" is noted in the remarks column in table 7, a graphical log showing the materials penetrated by the well is given in figure 18. Such a log will give the reader an idea of the materials that will be penetrated by drilling. Wells for which "anal." is noted in the remarks column have a chemical analysis listed in table 9. These analyses will give a general idea of the chemical quality of the ground water in the area.

Tables 1 and 2 summarize the water-bearing characteristics of, and chemical quality of water in, the water-bearing units in the Niagara Falls area. For information on present use and future development of ground water, refer to the section in the text entitled "Development of Ground Water."

# ...TOPOGRAPHY AND DRAINAGE

The Niagara Falls area is located in the lowland bordering the southern shore of Lake Ontario. It is a region of low relief except for the Niagara escarpment and the gorge of the Niagara River. The extremes of altitude for the area as a whole range from about 250 feet above mean sea level along the shore of Lake Ontario to 675 feet above mean sea level in southwestern Orleans County.

The Niagara escarpment crosses the area along an east-west line extending from the Niagara River on the west to and beyond the eastern boundary of the report area (fig. 2). The escarpment is an impressive 200-foot high cliff at the Niagara River, but gradually diminishes to a broad, gently sloping incline toward the east. The plain north of the escarpment is a flat area which slopes gently toward Lake Ontario. Relief is almost imperceptible throughout much of the lake plain. A rather low ridge extends more or less continuously east-west across the lake plain just north of the escarpment. This feature, known as the "beach ridge," marks a former shore line of Lake Ontario. The area south of the escarpment is also characterized by low relief, except in its eastern part, where small knobby hills and long, low ridges rise above the plain.

All streams in the Niagara Falls area flow into Lake Ontario either directly or by way of the Niagara River. The principal streams draining the area, as shown in figure 2, are Cayuga Creek, Twelve Mile Creek, Eighteen Mile Creek, and Oak Orchard Creek. With the exception of Oak Orchard Creek, the headwaters of all these streams are within the area. These streams have relatively small drainage areas and are characterized by very low flows whenever there are prolonged periods without precipitation. Most if not all streams that head on the lake plain north of the escarpment go dry for several months during each year. This is caused by the relatively impermeable nature of the rocks underlying the lake plain (shale overlain by clay and silt) which discharge insufficient ground water to the streams to maintain flow during dry periods.

The Niagara River is noteworthy for its high rate of flow and especially for the relative lack of variation in flow. The maximum daily discharge of record (274,000 cfs) is less than three times the minimum daily discharge of record (100,000 cfs). This contrasts sharply with many large rivers having maximum flows which are 30 or 40 times as large as their minimum flows. The reason for this relatively small variation is that the Niagara River drains four of the Great Lakes, which have a vast storage capacity and therefore are affected little by seasonal variations in precipitation. In fact, daily changes in the discharge rate of the Niagara River are caused by changes in the wind direction over Lake Erie or ice jams in the river itself, rather than by variations in precipitation. However, variations in the average annual discharge of the river are caused

by long-term differences in total precipitation and perhaps also by differences in evaporation as affected by air and water temperatures, wind speed, and other meteorologic elements. Discharge measurements of the Niagara River at Buffalo are made by the Corps of Engineers, U.S. Army, and are published annually in the water-supply papers of the U.S. Geological Survey.

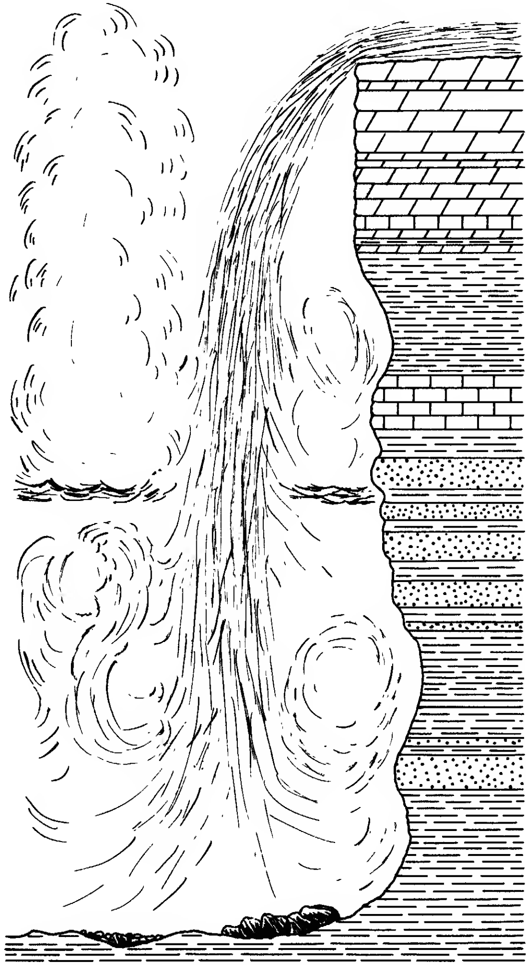
Niagara Falls is, of course, the most impressive physical feature in the area. The falls consist of two sections, the Canadian (or Horseshoe) Falls and the American Falls, which are separated by Goat Island. The Canadian Falls are much the larger cataract and discharge 90 percent of the flow of the Niagara River. The drop of the water at the brink of Niagara Falls is approximately 160 feet. For an excellent summary of the history and geomorphic development of the falls, the reader is referred to the U.S. Geological Survey Niagara Folio by Kindle and Taylor (1913).

# . . . GEOLOGY OF THE NIAGARA FALLS AREA

The geology of the Niagara Falls area is well understood both because of its simplicity and because of the excellent exposures of bedrock along the Niagara River gorge and the Niagara escarpment. The discussion of geology in this report is limited to those features which directly affect the water-bearing characteristics of the various geologic units. The reader desiring additional geologic information is referred to the reports by Grabau (1901) and Kindle and Taylor (1913).

A thin cover of unconsolidated deposits overlies the bedrock throughout most of the Niagara Falls area. These unconsolidated deposits were laid down during the closing phases of the great ice age (Pleistocene Epoch). The deposits consist of three types: (1) glacial till (locally called "stony hardpan") which is an unsorted mixture of boulders, clay, and sand which was deposited by the ice sheet that covered the area about 10,000 years ago; (2) clay, silt, and fine sand which was deposited in lakes that formed during the melting of the ice sheet; and (3) sand and gravel which was either deposited by streams carrying melt water from the ice sheet or was produced by re-working of till and other deposits along the shore of glacial Lake Iroquois (predecessor of the present Lake Ontario). The glacial till directly overlies the bedrock in most places. The lake-laid clay, silt, and sand overlie the till and are the materials found at the surface throughout a large part of the area. Sand and gravel occurs as isolated deposits and also composes a narrow "beach ridge" that extends in an east-west direction across the area (fig. 2 and pl. 3).

The bedrock in the Niagara Falls area consists of nearly flat-lying (horizontal) sedimentary rocks. The distinguishing feature of sedimentary rocks is their natural layering. Each layer is termed a bed and is separated from the bed above and below by a plane of separation called a bedding plane. The occurrence of sedimentary rocks in the Niagara Falls area can be described as "layer-cake geology" inasmuch as the various rock units crop out in "layer-cake" fashion at the brink of Niagara Falls as shown in figure 5. These units consist of dolomite, shale, limestone, and sandstone. Although the bedrock appears to lie horizontal to the eye, the beds actually dip to the south at about 30 feet per mile. The outcrop pattern produced by erosion of this simple geological structure is shown in plate 3. It can be seen that the area south of the Niagara escarpment is directly underlain by the Lockport Dolomite whereas the area north of the escarpment is underlain by the Queenston Shale. The intervening rocks of the Clinton and Albion Groups (fig. 5) crop out only along the escarpment and in the gorge of the Niagara River.



| System | | Group | Formation | Thickness [1/] (feet) | Description |
|---|---|---|---|---|---|
| Silurian | Middle | | Lockport Dolomite | 150 | Dark-gray to brown, massive to thin-bedded dolomite, locally containing algal reefs and small, irregularly shaped masses of gypsum. At the base are light-gray, coarse-grained limestone (Gasport Limestone Member) and gray shaly dolomite (DeCew Limestone Member of Williams, 1919). |
| | | Clinton | Rochester Shale | 60 | Dark-gray calcareous shale weathering light-gray to olive. |
| | | | Irondequoit Limestone | 12 | Light-gray to pinkish-white coarse-grained limestone. |
| | | | Reynales Limestone | 10 | White to yellowish-gray shaly limestone and dolomite. |
| | | | Neahga Shale of Sanford (1933) | 5 | Greenish-gray soft fissile shale. |
| | Lower | Albion | Thorold Sandstone | 8 | Greenish-gray shaly sandstone. |
| | | | Grimsby Sandstone of Williams (1914) | 45 | Reddish-brown to greenish-gray cross-bedded sandstone interbedded with red to greenish-gray shale. |
| | | | Unnamed unit | 40 | Gray to greenish-gray shale interbedded with light-gray sandstone. |
| | | | Whirlpool Sandstone | 20 | White, quartzitic sandstone. |
| Ordovician | Upper | | Queenston Shale | 1,200 | Brick-red sandy to argillaceous shale. |

1/ Average figure for area. Thickness at falls is not necessarily the same.

Figure 5.--Bedrock formations in the Niagara Falls area as exposed at the Horseshoe Falls. (Drawing modified after Gilbert, 1895.)

The bedrock surface is approximately parallel to the land surface throughout most of the Niagara Falls area. South of the Niagara escarpment, the top of the rock lies 5 to 15 feet below land surface. Local exceptions to this occur beneath isolated hills and ridges south of Medina where the depth to bedrock is about 30 to 40 feet. On the lake plain north of the escarpment, depth to rock varies from 5 to 90 feet, but is commonly at depths of 30 to 40 feet. The few irregularities in the surface of the bedrock appear to be due to minor features shaped by glacial or preglacial erosion. No major drainage channels of preglacial origin are known in the area.

# ...OCCURRENCE AND SOURCE OF GROUND WATER

Ground water in the Niagara Falls area occurs in both the unconsolidated deposits and in the bedrock; the mode of occurrence differs greatly between the two types of material. The occurrence and movement of ground water in both the unconsolidated deposits and the bedrock is shown schematically in figure 6. In the unconsolidated deposits water occurs in spaces between individual grains as shown by the blue dots in figure 6. In the bedrock water occurs in fractures in the rock as shown by the blue lines in figure 6. A knowledge of the location, size, and interconnection of rock openings is a basic prerequisite to the analysis of the availability and movement of ground water.

The openings between grains in the unconsolidated deposits are called primary openings because they have existed since the time the deposits were first laid down. These primary openings are also called interstices or pore spaces. The ratio of the volume of the pore spaces to the total volume of the deposit is the porosity. It is expressed as a percentage--for example, the porosity of a sand is about 30 percent and that of a clay is about 50 percent. The porosity is a measure of the void space and hence, the available space which can be filled with water. The permeability, which is the capacity of the deposit to transmit water, depends upon the size and shape of the pores and the degree of their interconnection. Deposits with large pores (sand and gravel) have much higher permeability than those with small pores (clay and silt). Permeability and other quantitative terms are discussed in a later section of this report.

Because the primary openings in bedrock have been closed by compaction and cementation, they are either absent entirely or so poorly interconnected that ground-water movement through them is negligible. Ground water occurs in the bedrock in secondary openings; that is, openings formed during the long period of time (millions of years) since deposition and compaction occurred. The secondary openings consist of (1) fractures and (2) cavities formed by solution of minerals. The fractures in the bedrock of the Niagara area probably consist of both faults and joints, a geological term used to include any fracture which disrupts the physical continuity of a rock mass. Joints are formed as a result of stresses applied to the rock. Two types of joints are present--(1) bedding joints which are parallel to the bedding (or natural layering of the rock) and (2) vertical joints which cut across the bedding approximately at right angles. Bedding joints containing water are shown by horizontal blue lines in figure 6 and vertical joints containing water are shown by vertical blue lines. As may be observed in the figure, the vertical joints containing water occur mostly in the upper 10 to 15 feet of rock whereas bedding joints are important water-bearing openings to a depth of 100 feet or more. Enlargement by chemical solution along either

type of joint will greatly increase its ability to transmit water. The porosity of the bedrock in the Niagara area is very low in comparison with the unconsolidated deposits--probably less than 1 percent. However, the permeability of the bedrock is much greater than that of clay, although less than that of sand or gravel.

A few feet or a few tens of feet below the earth's surface, the pore spaces in the unconsolidated deposits and the fractures in the bedrock are saturated with water, defined as "ground water." The upper surface of this zone of saturation is called the water table (fig. 6). The incompletely saturated zone above the water table is referred to as the zone of aeration and contains suspended water and air. There may be one or more water-bearing units below the water table, and each of these water-bearing units is an aquifer.

All ground water contains dissolved minerals in varying amounts. The amount of these dissolved constituents depends upon the ability and capacity of the water to dissolve minerals, and the type of geologic materials through which water has moved.

In the sections which follow, the water-bearing characteristics of the bedrock and unconsolidated deposits in the Niagara area are discussed. These discussions include: (1) a description of the geology of each unit with special reference to the occurrence of water-bearing openings; (2) the water-transmitting and water-storing capacity of the unit when such data are available; (3) yields of existing wells; and (4) a brief description of the chemical quality of the ground water in each unit. The information on the water-bearing characteristics of bedrock and unconsolidated deposits is summarized in table 1. The concentrations of selected chemical constituents and characteristics are listed in table 2. The classification of water-bearing units used in these tables is a simple breakdown into units with similar water-bearing properties. The areal extent of the water-bearing units and the location of all wells referred to in this report are shown in plates 1, 2, and 3. Plate 1 shows the location of wells and springs in the immediate vicinity of Niagara Falls, plate 2 shows the areal distribution of water-bearing units in the same area, and plate 3 shows the location of wells and springs and the areal distribution of water-bearing units for all of the Niagara Falls area not covered by plates 1 and 2. Additional information on all wells and springs shown in these plates is given in tables 7 and 8, respectively. Chemical analyses of ground water from selected wells and springs in the Niagara Falls area are listed in table 9.

## OCCURRENCE OF WATER IN BEDROCK

The bedrock is the principal source of ground water in the Niagara Falls area. However, the several bedrock units vary considerably in their ability to yield water to wells. For convenience in discussing water-bearing properties, the bedrock is divided into three units: (1) the Lockport Dolomite, (2) the Clinton and Albion Groups, and (3) the Queenston Shale. The Lockport is treated in considerable detail in the following sections both because it is the only important aquifer in the Niagara Falls area, and

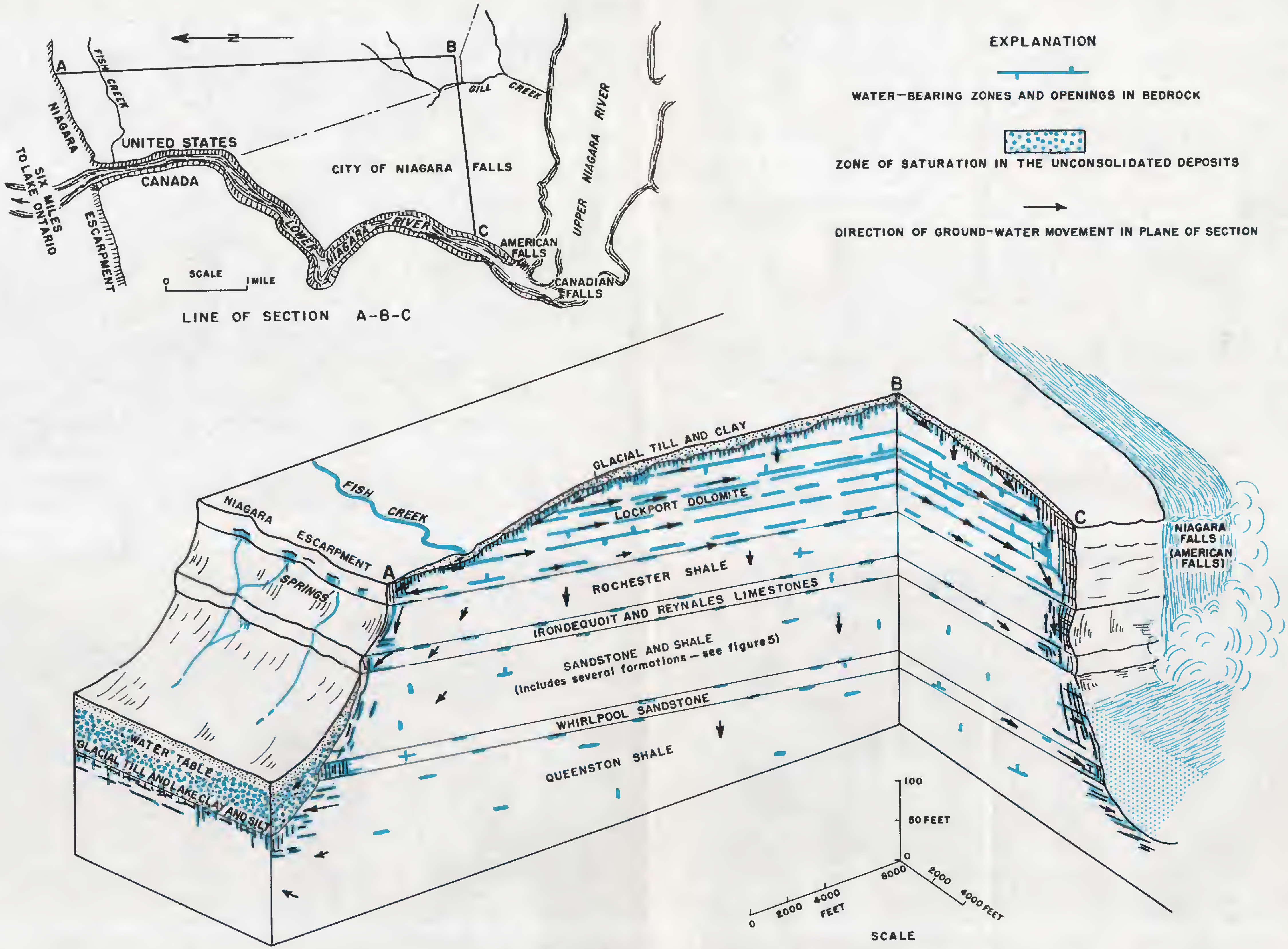



Figure 6.--Generalized block diagram showing occurrence and movement of ground water in the vicinity of the city of Niagara Falls prior to construction of the Niagara Power Project.

Table 1.--Water-bearing characteristics of unconsolidated deposits and bedrock in the Niagara Falls area

| | | Water-bearing unit | Thickness (feet) | Lithologic description | Yield of wells (gallons per minute) | Water-bearing characteristics |
|---|---|---|---|---|---|---|
| Unconsolidated deposits | | Sand and gravel | 0-70 | Fine- to medium-grained sand interbedded with coarse sand and pebbles. | 1-200 | Highly permeable. Sand and gravel generally occurs in thin deposits in isolated hills and in the "beach ridge." Thinness of the deposits and occurrence as topographic highs prevent development of large supplies. Wells are almost always adequate for domestic use and locally are adequate for small commercial supplies. |
| | | Lake clay, silt and fine sand | 0-90 | Laminated clay and silt with thin beds of fine sand. | Generally less than 1 | Clays and silts have very low permeability and yield little water. Water is found principally in the fine sand. Wells penetrating sand beds are generally adequate for domestic use. |
| | | Glacial till ("Hardpan") | 0-20 | Mixture of boulders and pebbles in a matrix of sand, silt, and clay. | Generally less than 1 | Water occurs principally in thin sand lenses in till and a "washed zone" at the top of bedrock. The washed zone often directly overlies a fractured zone in the bedrock forming a continuous aquifer. Wells penetrating the washed zone are usually adequate for domestic use. |
| Bedrock | Lockport Dolomite | Upper part and middle part | 110 | Dark-gray to grayish-brown dolomite, massive to thin bedded, locally containing algal reefs and small masses of gypsum. | Major part of area<br>2-110<br>(average 31) | Ground water occurs principally in 4 water-bearing zones parallel to bedding which are much more permeable than the surrounding rock. Vertical joints and small cavities formed by solution of gypsum yield small amounts of water, particularly in the upper 10 to 15 feet of rock. Wells are usually adequate for domestic and small commercial uses. |
| | | | | | Small area adjacent to upper Niagara River<br>50-2,200<br>(average 800) | Same as above except that the bedding joints, which comprise the principal water-bearing zones, and the vertical joints are hydraulically connected to the Niagara River. This permits the development of large supplies, much of which infiltrates from the Niagara River. Yields of individual wells vary greatly because of differences in the degree to which bedding joints have been widened by solution and variations in the number and spacing of vertical joints. |
| | | Lower part | 40 | Gray to brown dolomite, locally containing gypsum. Light gray coarse-grained limestone and shaly dolomite at the base. | ½-20<br>(average 7) | Ground water occurs principally in 3 water-bearing zones parallel to bedding. These 3 zones are less permeable than those in the upper and middle Lockport, causing wells to have lower yields. Wells are usually adequate for domestic uses except immediately adjacent to the Niagara escarpment where part of the Lockport is dewatered. |
| | | Clinton and Albion Groups | 200 | Light gray limestone grading downward into shale, alternating beds of shale and sandstone, and white sandstone at the base. | ½-5<br>(average 2½) | Ground water occurs principally in bedding joints and vertical joints within the sandstones and limestones. The limestone near the top (Irondequoit) and basal sandstone (Whirlpool) yield most of the water. The Rochester Shale at the top is almost impermeable and acts as a confining bed to the limestones and sandstones below. |
| | | Queenston Shale | 1,200 | Red sandy to clayey shale | 7<br>(in fractured or weathered zone) | Ground water occurs principally in a fractured zone in the top few feet of shale. The remainder of the formation is almost impermeable. Wells not obtaining water from the fractured zone are usually inadequate for domestic use. |

Table 2.--Selected chemical constituents and characteristics in ground water in the Niagara Falls area

| Water-bearing unit | | Bicarbonate (ppm) | Chloride (ppm) | Calcium, magnesium hardness (as $CaCO_3$) (ppm) | Specific conductance (micromhos at 25°C) | pH |
|---|---|---|---|---|---|---|
| Unconsolidated deposits 1/ (includes till, sand and gravel, and lake deposits) | Average | 365 | 118 | 545 | 1,350 | |
| | Range | 284- 414 | 26- 332 | 380- 686 | 727- 2,240 | 7.2-8.2 |
| | Number of analyses | 3 | 5 | 3 | 5 | 3 |
| Lockport Dolomite 2/ | Average | 289 | 234 | 960 | 1,760 | |
| | Range | 102- 460 | 3-1,530 | 120-2,660 | 335- 6,390 | 6.6-8.0 |
| | Number of analyses | 33 | 52 | 32 | 33 | 31 |
| Clinton and Albion Groups 1/ | Average | 516 | 1,710 | 1,800 | 4,090 | |
| | Range | 159-1,440 | 54-4,450 | 1,260-2,790 | 823- 7,720 | 6.5-7.1 |
| | Number of analyses | 4 | 4 | 4 | 3 | 4 |
| Queenston Shale 3/ | Average | 228 | 646 | 883 | 3,800 | |
| | Range | 9- 372 | 90-3,150 | 219-1,910 | 927-11,900 | 5.7-7.8 |
| | Number of analyses | 10 | 10 | 10 | 8 | 10 |

1/ Values may not be representative of water-bearing unit throughout the entire area because of small number of samples.

2/ Includes only the first analysis for those wells for which several analyses were made. Does not include analyses of two brine samples.

3/ Does not include saline water samples from test holes at the Robert Moses Generating Plant.

because studies made on the Lockport may contribute to a better understanding of the occurrence of ground water in bedrock generally. The Queenston Shale and Clinton and Albion Groups are poor aquifers in comparison to the Lockport Dolomite, and less is known of their water-bearing characteristics.

## LOCKPORT DOLOMITE

### Character and extent

The Lockport Dolomite is the uppermost bedrock formation in about one-third of the Niagara Falls area. Its outcrop area extends from the Niagara escarpment on the north to the southern boundary of the area covered by this report except in two small areas that may be underlain by the Salina Group. (See plate 3.) One of these areas is in the vicinity of the hamlet of Nashville and the other is in the extreme southeast corner. Because of a lack of rock outcrops in these areas the position of the contact between the Lockport and the Salina cannot be accurately determined. However, the Salina Group is not discussed as a separate water-bearing unit in this report because at most only a few feet of it occurs in the area. Continuous exposures of the Lockport are found along the gorge of the Niagara River and along the Niagara escarpment. The formation is about 150 feet thick in the southern part of the area but has been eroded to a thickness of only about 20 feet along the escarpment (pl. 2). The excellent exposures at Niagara Falls (fig. 5), where the Lockport forms the lip of the Falls, are shown in many geology textbooks as a classic example of flat-lying sedimentary rocks. Throughout most of the remainder of the area, which is relatively flat, the Lockport is concealed by a thin cover of glacial deposits.

As its name implies, the Lockport Dolomite consists mainly of dolomite; however, the formation also includes thin beds of limestone and shaly dolomite near the base. The Lockport consists of five lithologic types which, from top to bottom, are:

(a) brownish-gray, coarse- to medium-grained dolomite, locally saccharoidal with thin intervals of curved bedding (algal structures).

(b) gray to dark-gray, fine-grained dolomite, containing abundant carbonaceous partings.

(c) tannish-gray, fine-grained dolomite.

(d) light-gray, coarse-grained limestone containing abundant crinoid fragments (Gasport Limestone Member).

(e) light-gray shaly dolomite, laminated in part (DeCew Limestone Member of Williams, 1919).

Fisher (1960) divides the Lockport Dolomite into six units based on fossils as well as rock types. An excellent discussion of the stratigraphy of the

Lockport, including measured sections in the Niagara Falls area, is given in the recent thesis by Zenger 1/.

The detailed breakdowns by Fisher and Zenger, although helpful for geologic mapping and correlating the Lockport with rocks of similar age elsewhere, are not necessary in descriptions of the water-bearing properties of the formation. For this purpose the Lockport is subdivided as follows (figure 5 and table 1): (1) upper and middle parts of the Lockport, and (2) lower part of the Lockport, including the Gasport Limestone Member and DeCew Limestone Member of Williams (1919).

Most of the beds in the Lockport are described as either "thick" (1 foot to 3 feet) or "thin" (1 inch to 1 foot). However, massive beds up to eight feet thick and very thin beds (1/4 to 1 inch) occur within the formation. The bedding is generally straight, but curved bedding occurs in some places in the upper part of the formation. The curved bedding is caused by dome-shaped algal structures called "stromatolites" (Zenger, p. 140). These reefs (bioherms), which occur as lens-like masses up to 50 feet across and 10 to 20 feet thick, contain no bedding.

Gypsum (calcium sulfate) is common in the Lockport, occurring chiefly as small irregularly shaped masses (commonly 1/2 to 5 inches in diameter) and as selenite. Sulfide minerals, particularly sphalerite (zinc sulfide), galena (lead sulfide), and pyrite (iron sulfide) occur as particles disseminated throughout the formation.

## Water-bearing openings

Types.--Ground-water occurs in the Lockport Dolomite in three types of openings: (1) bedding joints which constitute at least seven important water-bearing zones, (2) vertical joints, and (3) small cavities from which gypsum has been dissolved. Of these, the bedding joints are the most important and transmit nearly all the water moving through the formation. The three types of openings were observed in the dewatered excavations for the conduits of the Niagara Power Project. (See the description of the power project in the introduction and the location of the conduits in figure 3.) The rock faces along the four-mile length of the conduits provided an unequaled opportunity to study water-bearing openings in the entire stratigraphic thickness of the Lockport and to observe the lateral extent of these openings for a few thousand feet. At the time the observations were made (July - August 1960), approximately one-third of the length of the conduits was available for inspection by the writer.

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1/ Zenger, D. H., 1962, Stratigraphy of the Lockport Formation (Silurian) in New York State: Unpublished doctoral thesis, Cornell University.

The bedding joints, which transmit most of the water in the Lockport, are fractures along prominent bedding planes which have been widened very slightly by solution of the rock. These planar openings persist laterally for distances of at least 3 to 4 miles. The separation along individual bedding joints is small (less than 1/8 inch). However, their continuity makes them effective "conduits" for movement of ground water. The large water-transmitting capacity of the bedding joints was shown by the fact that they supplied nearly all the ground-water seepage entering the conduit excavations. The almost continuous lines of seepage from bedding joints was strikingly apparent in the conduits. Figure 7 shows seepage from two bedding joints.

The bedding joints transmitting ground water comprise at least seven distinct water-bearing zones within the Lockport. These water-bearing zones could be traced laterally for distances of 1 to 4 miles. Figure 8 shows the stratigraphic position and part of the lateral extent of the seven zones. The water-bearing zones have been numbered from 1 to 7 from bottom to top. The three sections shown in figure 8 were surveyed by transit and then correlated on the following basis: (1) lithologic similarities, (2) laterally tracing seepage from individual water-bearing zones, and (3) in the case of section A, the distance above the Rochester Shale as shown by core holes. The correlation of water-bearing zone 6 between sections A and B has been changed slightly from an earlier published version (Johnston, 1962, fig. 110.2).

A water-bearing zone may consist of a single open bedding joint (for example zone 4, section C, fig. 8) or it may consist of an interval of rock measuring up to one foot in thickness containing several open bedding joints (zone 7, section A, fig. 8). Where the water-bearing zone consists of several joints, the open joint transmitting most of the water at one locality may "pinch out" laterally and be replaced by another open joint within the same zone elsewhere. For example, at section B (fig. 8) most seepage from water-bearing zone 6 came from a joint at the top of a thin-bedded interval; however, at section A all seepage came from a joint at the bottom of the interval. The opening along one bedding joint thus becomes closed while a parallel opening along an adjacent bedding joint becomes open.

The water-bearing zones occur most commonly within intervals of the Lockport containing thin beds from 1/4 to about 4 inches thick which are directly overlain by thick or massive beds. The thin beds generally contain open vertical joints, and at the intersection of such vertical joints with open bedding joints ground-water seepage is greatest. At a few such points water was observed to squirt from the openings into the conduit excavations in much the same manner as it would from a broken water pipe. It seems likely that open joints occur most commonly in thin-bedded intervals because the greater structural rigidity of the overlying thick or massive beds permits the joints to remain open.

Water-bearing zones occur less commonly within thick-bedded intervals. In such cases all seepage occurs from one distinct bedding joint rather than from several joints. Seepage from zone 4 at section C (fig. 8) came from one prominent bedding joint within an interval of beds averaging one foot in thickness. This bedding joint is open about 1/16 to 1/8 inch locally and appears to transmit as much ground water as any water-bearing zone in the Lockport.

Figure 7.--Seepage from bedding joints in the Lockport Dolomite. View is of east wall of conduit number 1, looking south from Porter Rd. bridge. (Photograph by the Power Authority of the State of New York.)

Vertical joints, excluding those mentioned above which are associated with open bedding joints in thin-bedded intervals, are not important water-bearing openings in the Lockport, except within the top few feet of rock. Two prominent sets of vertical joints exist in the Niagara Falls area; one set oriented N. 65° E. and the other N. 30° W. These joints are fractures in the rock which must be widened by solution before they can become effective water-bearing openings. Such widening is apparent in outcrops of the Lockport. For example, open vertical joints are particularly

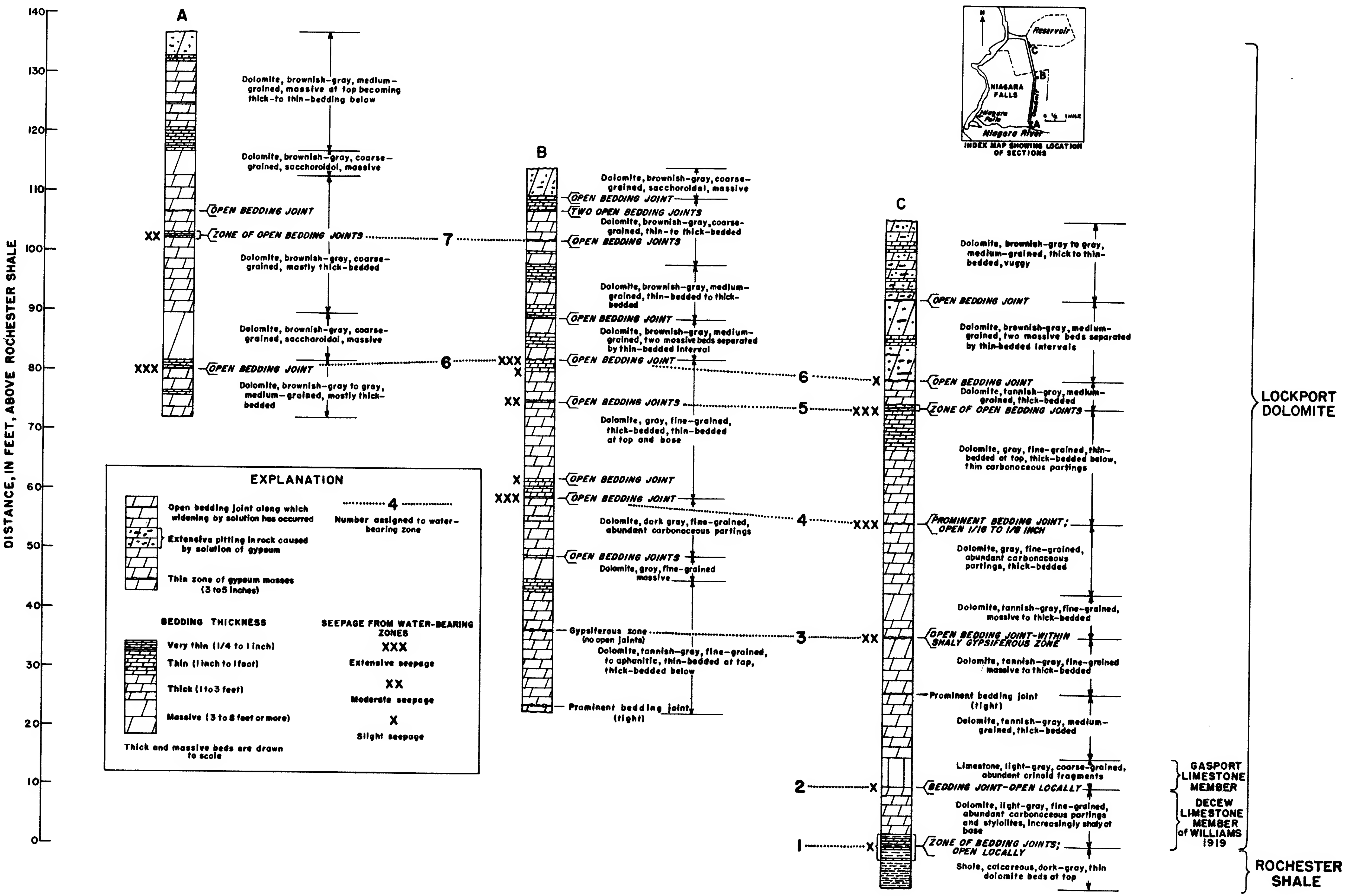


Figure 8.--Sections showing position of water-bearing zones in the Lockport Dolomite in the vicinity of Niagara Falls.

prominent in the rock cliffs of the Niagara River Gorge and the Niagara escarpment. The width of these joints in many areas exceeds several inches. However, in fresh exposures of the Lockport, such as the conduit excavations, vertical joints are tight and often not apparent to the eye except in the upper few feet of the rock.

Cavities formed by solution of gypsum occur in the Lockport Dolomite. These cavities range in size from 1/16 inch or less to 5 inches but are generally less than one inch in size. The cavities are formed by the dissolving of gypsum by percolating ground water, and there is a complete range in the development of cavities from voids containing no gypsum to pin-point openings in gypsum nodules. The cavities are most abundant in the top 10 to 15 feet of rock but they also occur along water-bearing zones in the lower part of the rock (for example, water-bearing zone 3, section C, fig. 8). In the upper part of the rock, the abundance of cavities locally gives a vuggy appearance to the dolomite.

The cavities in the Lockport resulting from solution of gypsum increase the ability of the Lockport to store water (porosity) but probably have little effect on the water-transmitting ability of the formation. This is because the water-transmitting ability (or permeability) is dependent upon the size of the continuous openings rather than the size of isolated openings. Thus, the relatively thin but continuous bedding joints determine the permeability of the Lockport rather than the larger but isolated cavities resulting from solution of gypsum.

The character and interrelationships of the three types of water-bearing openings described above result in two distinct sets of ground-water conditions in the Lockport Dolomite: (1) a moderately permeable zone at the top of rock, generally 10 to 15 feet thick, characterized by both vertical and bedding joints that have been widened by solution and by gypsum cavities, and (2) the remainder of the formation consisting of seven permeable zones (composed of bedding joints) surrounded by essentially impermeable rock.

Areal extent.--Relatively little is known about the areal extent of the seven water-bearing zones in the Lockport Dolomite, except as observed in the conduits (fig. 8). Many of the individual bedding joints tend to "pinch out" laterally, and be replaced by adjacent joints in the same zone. Such "pinching out" of joints transmitting water was observed in the conduits. Observations in the conduits and data from wells suggest that a few of the zones may persist for tens of miles. The water-bearing zones of greatest areal extent are those which occur at distinct lithologic breaks in the formation. Zone 1, occurring at the base of the Lockport (fig. 8), is frequently reported to be a water-bearing zone by drillers throughout the area. Zone 2, which occurs at the contact between coarse-grained limestone (Gasport Member) and shaly dolomite (DeCew Limestone Member of Williams, 1919) is the source of most of the springs along the Niagara escarpment. Other water-bearing zones, not located at contacts between distinct lithologic units, probably tend to pinch out within a few miles. In summary, at any point in the area, a number of water-bearing zones parallel to bedding exist in the Lockport. All such zones, however, are not necessarily equivalent to the seven water-bearing zones observed in the conduit excavations at Niagara Falls.

It was also noted in the conduit excavations that there were places, even along the most prominent water-bearing zones, where no seepage was occurring. Many such places doubtless represent natural supports for the overlying rock because no extensive horizontal opening below the earth's surface can exist for any great distance. Little is known either about the nature or the size of these support areas or the distance between them. The available data suggest, however, that they encompass an area of at least a few square feet and are separated by a few tens of feet. It may be expected that with depth the size of the supports increases and the distance between them decreases.

The occurrence of ground water principally in zones parallel to bedding is probably characteristic of flat-lying Paleozoic carbonate rocks in many other places. This type of occurrence was reported by Trainer and Salvas (1962, p. 42) in the Beekmantown Dolomite near Massena, N. Y. They observed that "... The openings which are horizontal or gently dipping, and most of which are probably joints or other fractures parallel to the bedding of the rocks, are wider and more numerous than the steeply dipping openings." Although the Beekmantown Dolomite is of an older geologic age than the Lockport, certain similarities exist between the two formations: (1) both units consist of indurated Paleozoic dolomite and limestone; (2) both units are gently dipping, neither having been subjected to extensive folding and faulting which would result in the development of more prominent vertical joints or fractures associated with faulting; (3) both units were subjected to scouring by ice during glaciation within the last 10,000 to 15,000 years and thus, the extensive solution features common to limestones and dolomites in unglaciated areas have not had time to develop. It seems probable that any flat-lying carbonate rock, possessing the characteristics just stated, will contain ground water principally within joints parallel to bedding.

Origin of water-bearing openings.--The origin and the sequence of development of both the vertical joints and bedding joints are of considerable importance in developing an understanding of the occurrence of water in bedrock. Although it was not possible to investigate the origin or the development during this study, speculations based on fundamental principles of geology, especially regarding the origin of the bedding joints, may be worthwhile.

It is widely recognized that joints are formed by forces which tend to pull the rock apart (tension joints) or slide one part of the rock past an adjacent part (shear joints); see, for example, the discussion by Billings (1954, p. 115). The vertical joints were probably formed by a combination of tension and shear forces during or following the folding of the Appalachian Mountains about 200 million years ago. The bedding joints represent tension fractures that formed as a result of expansion of the rock in a vertical direction during more recent geologic time. The Lockport as recently as 200 million years ago was doubtless buried under thousands of feet of other rocks in the Niagara Falls area just as it is at the present time in the southern part of New York State. During the erosion of the overlying rocks the Lockport expanded vertically. The expansion caused fracturing to occur along bedding planes which are natural planes of weakness in the rock and which are approximately parallel to the land surface. Vertical joints, being at right angles to the land surface were little affected by the removal of the overlying rock.

The bedding joints may have been further expanded by stresses produced in the rock during the recession of the glaciers 10 to 15 thousand years ago. The melting of several thousand feet of ice was doubtless accompanied by an expansion of the rock. This expansion either resulted in an enlargement of existing bedding-plane openings or the formation of new openings along other bedding planes.

In recent geologic times, chemical solution of the rock has widened both the vertical and bedding joints. In the already well-developed openings along bedding joints, slight widening by solution has occurred to depths of 100 feet or more. Enlargement of vertical joints, in contrast, is generally restricted to the upper 10 to 15 feet of rock. Cavities formed by solution of gypsum exist where water moving along joints in the Lockport came into contact with gypsum. Gypsum is much more soluble than dolomite; thus, openings formed by the solution of gypsum are wider than other openings along joints. Water moving down vertical joints has dissolved the gypsum to a depth of about 15 feet leaving irregularly-shaped cavities, and water moving along bedding joints has dissolved gypsum to depths of at least 70 feet.

## Water-bearing characteristics

Ground water exists in the Lockport Dolomite under artesian, semi-artesian, and unconfined conditions. Unconfined conditions occur where the water table is the upper surface of the zone of saturation within an aquifer. The water table in an unconfined aquifer moves freely upward as water is added to storage, or downward as water is taken from storage. In contrast, an artesian aquifer contains water which is confined by an overlying impermeable bed and which is under sufficient pressure to rise above the top of the aquifer. The level to which water in an artesian aquifer will rise forms an imaginary surface which is called a piezometric surface. Water levels in artesian aquifers change in response to pressure changes on the aquifer rather than to changes in the amount of water stored in the aquifer.

Both artesian and water-table conditions exist in the Lockport. However, artesian conditions predominate. Figure 9 illustrates the occurrence of both artesian and water-table conditions in the Lockport. The wells shown in the diagram are cased through the clay and silt, but are open holes in the bedrock. A packer is installed in each well which tapped water at two or more distinct levels. The packers make possible the measurement of two distinct water levels in each well; a water level above the packer reflecting conditions in the upper part of the rock and a water level below the packer reflecting conditions in the lower part of the rock.

In the upper part of the rock, either artesian or water-table conditions may exist locally. The clay and silt overlying the Lockport are less permeable than the rock and thus act as a confining bed. Artesian conditions exist where the water in the Lockport has sufficient head to rise above the bottom of the overlying clay and silt. In contrast, unconfined (or water-table) conditions exist where the water level occurs within the fractured upper part of the rock, as at well 309-901-5 in figure 9. Locally a "washed till" or dirty gravel zone occurs just above the top of rock. In these

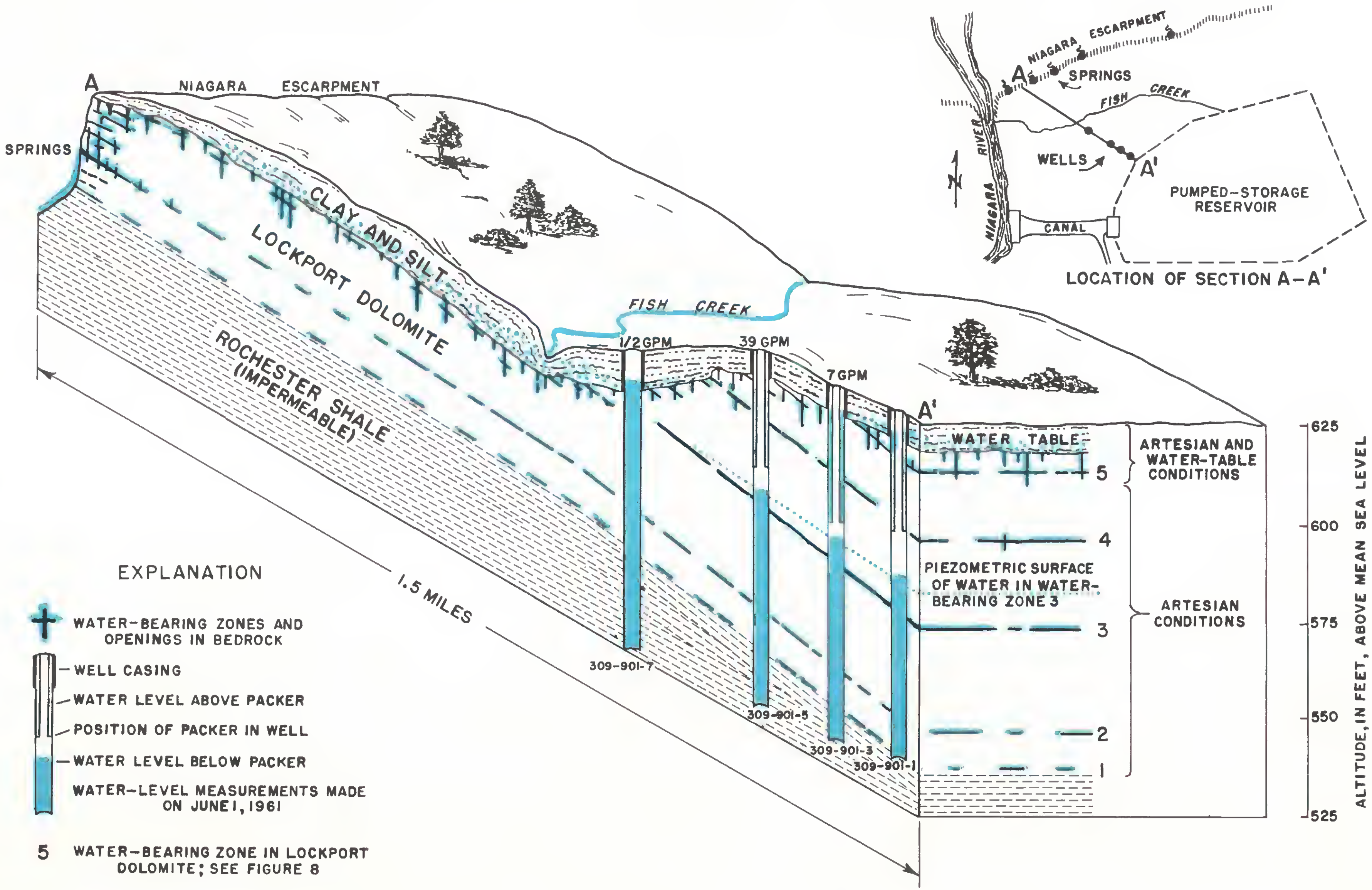


Figure 9.--Block diagram showing the occurrence of ground water in the Lockport Dolomite.

localities good connection probably exists between the bedrock and the overlying till or gravel, and the upper part of the rock and washed till zone together form a continuous semi-confined aquifer.

In the lower part of the rock, artesian conditions occur exclusively. The seven water-bearing zones in the Lockport are surrounded by essentially impermeable rock and therefore act as separate and distinct artesian aquifers. The hydraulic nature of the water-bearing zones was observed during the drilling of observation wells in the vicinity of the Niagara Power Project. These wells, whose locations are shown in plate 1, were drilled to observe the effects of the reservoir on ground-water levels in the area. The piezometric level for each successively lower water-bearing zone is lower than for the zone just above it in most of the wells. The reasons for this will be discussed in the section entitled "Ground-Water Movement and Discharge." During construction, the water level in the wells progressively declined in a steplike sequence as the wells were drilled deeper--that is, when a well had been drilled through the uppermost water-bearing zone, the water level in the well remained approximately at a constant level until the next lower zone was penetrated, at which time the water level abruptly declined to the piezometric level of the next lower zone. The difference between the piezometric levels of any two water-bearing zones is large, and in some places is comparable to the distance between zones. If no packer is installed in a well tapping two water-bearing zones, the upper zone will continue to drain into the well indefinitely. This condition exists in a few of the power project observation wells. In these wells the sides of the well remain wet from the level of the upper zone down to the water level in the well. The nature of the water-bearing zones as described above substantiates the reports by drillers and others of "finding water and losing it" in a well, or of wells with "water running in the top and out the bottom." These phenomena occur in some wells tapping two or more water-bearing zones in the Lockport Dolomite.

A well drilled into the Lockport may penetrate several water-bearing zones, but only one of the zones may be hydraulically effective at the site of the well. This is the case for wells 309-901-1, 3, and 5 shown in figure 9. These wells are open below the packers to zones 1, 2, and 3. However, because the water levels observed below the packers in these three wells apparently represents the piezometric surface of zone 3, zones 1 and 2 are not believed to contain effective openings at the sites of the wells. A well also may be drilled through the section occupied by several zones and not be open to any of them. For example, well 309-901-7 shown in figure 9, is apparently open only to the weathered zone at the top of rock.

## Yield and specific capacity of wells

The yield of a well in the Lockport Dolomite depends mainly upon which water-bearing zone or zones are penetrated and the degree to which the bedding joints comprising the zones are open to the well. Near the top of rock, the number of open vertical joints and gypsum cavities penetrated may also be important. The average yield of 56 wells tapping the upper and middle parts of the Lockport (which includes water-bearing zones 4 through 7) is 31 gpm (gallons per minute). In contrast, 15 wells penetrating only

the lower 40 feet of the Lockport (which includes water-bearing zones 1, 2, and 3) have an average yield of 7 gpm. The yields of individual wells range from less than 1 gpm to 110 gpm. (These figures do not include a few exceptionally high yield wells which obtain water by induced infiltration from the Niagara River and which are discussed in a following paragraph.) Wells tapping the same water-bearing zone may have different yields. For example, wells 309-901-3 and 309-901-5, which are 500 feet apart and tap water-bearing zones 1 through 4 (fig. 9) yielded 7 gpm and 39 gpm, respectively, before the packers were installed. The bedding joints comprising the water-bearing zones are thus more open at well -5 than at well -3.

Increases in yield during drilling in the Lockport Dolomite occur abruptly rather than gradually. As drilling proceeds through the rock, relatively little increase in the yield of a well will be observed until a water-bearing zone is tapped. At that time a marked increase in yield usually occurs. For example, during the drilling of well 308-901-7, the bailing rate abruptly increased from 12 to 50 gpm when water-bearing zone 5 was tapped. During the drilling of well 308-900-21, three distinct increases in yield were observed. The yield, which was 3 gpm at 17 feet (water-bearing zone 7), increased to 9 gpm at 22 feet (an open vertical? joint or solution cavity?) and abruptly increased to 30 gpm at 34 feet (water-bearing zone 6).

Wells in an area about a half mile wide adjacent to the Niagara River above the falls have substantially higher yields than wells elsewhere in the area. The higher yields in this area are caused by two conditions: (1) the Lockport Dolomite is thickest in the area, and (2) more importantly, conditions are favorable for the infiltration of water from the Niagara River. The greater thickness of the Lockport provides the maximum number of water-bearing zones to supply water to the wells. The Niagara River provides an unlimited source of recharge to the water-bearing zones.

Evidence that a substantial part of the water pumped is supplied by induced infiltration from the Niagara River is indicated by the high yields, which exceed 2,000 gpm at some wells, and the chemical character of the water. The chemical composition of the water in well 304-901-6 (which has been pumped at 2,100 gpm) is more similar to Niagara River water than "typical" ground water in the Lockport. (See the following discussion of the chemical character of water and figure 11.) Similar infiltration of Niagara River water into the bedrock at Tonawanda, N. Y., a few miles south of Niagara Falls, was described by Reck and Simmons (1952, p. 19-20).

Infiltration from the river can occur where pumping has lowered ground-water levels below river level to such an extent that a hydraulic gradient is created between the river and the wells. The amount of the infiltration depends on the gradient and the nature of the hydraulic connection between the river and Lockport. The hydraulic connection is controlled by the character of the river bottom. Throughout most of its length in the Niagara Falls area the bottom of the river is covered by a layer of unconsolidated deposits including both till and clay and silt. This layer was found to be from 10 to 20 feet thick in the vicinity of the Niagara Falls water-system intake. (See logs 304-900-i and -j in figure 19.) In the section of the river occupied by rapids, extending a half mile or more above the falls, the bottom has been scoured clean by the river. Where the layer of unconsolidated deposits is present its low permeability greatly retards infiltration. Where the layer is thin or absent infiltration can readily occur.

One of the most striking features in plate 2 is that all wells yielding more than 1,000 gpm are located in a narrow band that intercepts the river about two miles east of the falls. This band trends in a northeasterly direction roughly parallel to one of the two major directions of vertical jointing. Thus, the very high yields may be caused by a greater abundance of vertical joints within the band of high-yielding wells. Vertical joints provide avenues through which water could readily move from the river downward to the bedding joints comprising the water-bearing zones in the Lockport Dolomite.

Wells in the Lockport Dolomite are almost always adequate for domestic needs of a few gallons per minute. Supplies of 50 to 100 gpm, which are adequate for commercial uses and small public supplies, can be obtained in much of the area underlain by the upper part of the Lockport (pl. 2). Large supplies (over 1,000 gpm), as previously noted, are available only in a small area adjacent to the Niagara River.

Wells inadequate for domestic needs are occasionally reported. All wells that are perennially inadequate are located near the Niagara escarpment and therefore tap only the lowest and least permeable water-bearing zones (1, 2, and 3) in the Lockport. Throughout the area a few shallow wells that derive nearly all their water from a single water-bearing zone become inadequate during the summer and autumn of some dry years. Such is the case with well 308-853-1. This well is 27 feet deep and reportedly obtained over 50 gpm from a water-bearing zone 17 feet below land surface. During the drought in 1960, this zone was dewatered as the water table declined in the fall of the year, and the yield of the well quickly declined to less than 1 gpm. The inadequacy of some wells in the Lockport Dolomite can normally be overcome by deepening the well until it penetrates one or more lower water-bearing zones.

Information on the specific capacity of a well is more meaningful than a simple statement of yield. The specific capacity is the yield per unit drawdown, generally expressed as gallons per minute per foot of drawdown. For example, well 307-903-1 was pumped at 20 gpm with 54 feet of drawdown which indicates a specific capacity of 0.37 gpm per foot. The yield and the drawdown for a number of wells in the Lockport are shown in plates 2 and 3. These data must be used with care as they apply only so long as no part of the formation is dewatered.

As water-bearing zones in the Lockport are dewatered, the specific capacity declines. The decline in specific capacity caused by dewatering a water-bearing zone is shown by the data obtained during a pumping test on well 309-859-1. This well was pumped at 2.2 gpm with 5.0 feet of drawdown for 70 minutes--specific capacity of 0.44 gpm per foot. After 70 minutes, water-bearing zone 3 was partially dewatered and a drawdown of 8.2 feet was required to maintain the pumping rate of 2.2 gpm. This indicates a specific capacity of 0.27 gpm per foot. At the time the well was drilled, it was bailed at 3 gpm with a drawdown of about 60 feet. Thus, during the bailing the entire 42 feet of Lockport penetrated by the well was dewatered. The specific capacity of the well with the Lockport dewatered is 0.07 gpm per foot (3 gpm with 42 feet of drawdown) compared to 0.44 gpm per foot with no dewatering.

## Permeability, transmissibility, and storage coefficients

Permeability (P), transmissibility (T), and storage (S) coefficients are terms used to describe the ability of an aquifer to transmit water and to release water from storage. These three terms are called aquifer constants. The coefficient of permeability is defined as the rate of flow of water in gallons per day through a cross-sectional area of the aquifer of one square foot under a unit hydraulic gradient (1 foot vertical drop for each 1 foot of horizontal distance) at a temperature of 60°F. The coefficient of transmissibility is the rate of flow, at the prevailing water temperature, in gpd (gallons per day), through a 1-foot-wide vertical strip of aquifer extending the full saturated height of the aquifer under a unit hydraulic gradient. The term transmissibility was introduced by Theis (1935) to describe the water-transmitting capacity of an aquifer as a whole. It can be seen from the definitions of transmissibility and permeability stated above, that the coefficient of transmissibility is equal to the coefficient of permeability multiplied by the saturated thickness of an aquifer. The coefficient of storage is defined as the volume of water an aquifer releases from or takes into storage per unit surface area (such as per square foot) of the aquifer per unit change in head normal to that surface (Ferris and others, 1962, p. 74).

Values for T and S given in this report were obtained from pumping tests in the field. Values for P of the Lockport Dolomite obtained from laboratory tests would be highly misleading because of the water-bearing characteristics of the formation. A sample of unjointed rock from the Lockport would give an extremely low value for P. In contrast, a rock sample collected at a water-bearing zone, and therefore containing open bedding joints, would give a very high value for P. Values for T obtained from analysis of pumping-test data are composite figures for the Lockport which average the very low permeability of unjointed rock with the very high permeability of the water-bearing zones. The values for T obtained from pumping-test data, therefore, more truly describe the water-transmitting ability of the formation as a whole.

The two methods most widely used to analyze pumping-test results for T and S are the Thiem and the Theis methods. Both methods are applications of Darcy's law, which states that the quantity of water discharged through porous material varies directly with the permeability, hydraulic gradient, and cross-sectional area through which the discharge occurs. The Thiem equation is used to analyze tests in which equilibrium conditions have been reached; that is, when the drawdown of water levels has stabilized in both the pumping well and observation wells. The Theis equation does not require that equilibrium conditions be reached. A thorough discussion of both methods, including the assumptions on which each are based, is given in a recent report on the theory of aquifer test (Ferris and others, 1962). The following discussion of transmissibility and storage coefficients of the Lockport Dolomite does not require familiarity with the methods used in analyzing pumping tests, although such knowledge would be helpful.

Table 3 lists the values for T and S obtained from seven aquifer tests in the Lockport Dolomite. Five of the seven tests were conducted by Geological Survey personnel assisted by personnel of Uhl, Hall & Rich, consulting

Table 3.--Summary of aquifer tests in the Lockport Dolomite

| Pumping well | Observation wells | Date of test | Pumping rate (Q), (gallons per minute) | Transmissibility (T) (gallons per day per foot) | Storage coefficient (S) | Saturated thickness (feet) | Duration of test | Remarks |
|---|---|---|---|---|---|---|---|---|
| 304-901-2 | 304-901-1<br>304-901-3 | July 1947 | 1,740 | 68,000 | --- | 136 | -- | Thiem formula applied to stabilized drawdown in two observation wells. Yield of well partly supplied by induced recharge from Niagara River. Observation wells located 11 and 550 ft from pumping well at approximately same distance from river as pumping well. Pumping-test data supplied by E. I. du Pont de Nemours & Co. |
| 305-900-1 | 2 observation wells, unnumbered | Nov. 4-7, 1958 | 950 | 17,000 | --- | 140 | 74 hours | Pumping rate at start of test was 1,100-1,200 gpm. Pumping rate stabilized at 950 gpm with 82 ft of drawdown after 66 hrs. Thiem formula applied to stabilized drawdown in two observation wells 400 and 600 ft away. Yield of well probably partly supplied by induced recharge from Niagara River. Pumping-test data supplied by Layne-New York Co., Inc. |
| 308-900-15 | 308-900-1 | Nov. 21-22, 1961 | 5.5 | 900 | .00003 | 17 | 12 hours | Theis plots of drawdown and recovery show recharging boundary (Niagara Power Project Reservoir). |
| 308-900-16 | --- | May 10, 1962 | 3.2 | 700 | --- | 36 | 1½ hours | Recovery measured in closed-off flowing well. Theis recovery formula applied to recovery of water level. |
| 309-859-1 | 309-859-2<br>309-859-3 | Nov. 4, 1960 | 2.2 | 1,000 | .0003 | 38 | 3½ hours | Values of T and S calculated from drawdown of water level in observation well 309-859-2. Value of T declined from 1,000 to 130 as Lockport was dewatered during test. Full discussion of this test, utilizing the Theis method of analysis, given in text. |
| 309-859-2 | 309-859-1<br>309-859-3 | Oct. 11, 1960 | 2.2 | 330 | .00001 | 42 | 2 hours | Values for T and S calculated from drawdown of water level in observation well 309-859-1. Excellent match on Theis type curve. Value of T is representative for lower part of Lockport. |
| Dewatered conduit excavations | 308-900-1<br>308-900-3<br>308-900-7<br>308-900-9 | Oct.-Nov. 1960 | 1,000 (variable from 760 to 1,190) | 2,300 | --- | 110 | 2 months | An average of 1,000 gpm was pumped to keep an 18,000-foot-long section of conduit excavations dewatered. Darcy equation was used to calculate T; gradient was calculated from wells to conduits. Value of T is probably most representative value for Lockport as a whole. |

engineers for the Niagara Power Project. Two of the tests were conducted by private companies, as noted in table 3, and aquifer constants were calculated from the reported pumping-test data.

The coefficient of transmissibility of the Lockport Dolomite, as shown in table 3, ranges from 330 gpd per foot to 68,000 gpd per foot. The value of T of 2,300 gpd per foot derived from an analysis of data from the conduit excavations is probably the most representative value for the Lockport as a whole. This value, as noted in table 3, was obtained from a test which considered an 18,000-foot-long section of dewatered conduit excavations as a well. An average of 1,000 gpm of water was pumped to keep this section of conduits dewatered during a two-month period in 1960 (the conduits had been dewatered at that time for approximately 2 years). By measuring water levels in wells adjacent to the conduits, the gradients that supplied the 1,000 gpm to the conduits were calculated. Application of the average gradient (0.017 foot per foot) and the pumping rate of 1,000 gpm to the Darcy equation gave a T of 2,300 gpd per foot. This analysis assumes that the observation wells, which were 2,000 to 3,600 feet from the conduits, indicate the regional gradient toward the conduits and not the water level of specific water-bearing zones. However, at best, the value for T is only approximate.

The highest value of T, that of 68,000 gpd per foot, represents the optimum water-transmitting ability of the Lockport Dolomite. Well 304-901-2, which gave this value, fully penetrates the entire thickness of the Lockport, and during drilling reportedly tapped six distinct water-bearing zones (graphical log shown in fig. 18). This well is located 200 feet from the Niagara River and is partly supplied by induced recharge from the river.

The lowest value for T listed in table 3, 330 gpd per foot, was obtained from a well which penetrates the lower 40 feet of the Lockport. This low value for T is believed to be representative of the lower part of the formation which contains the least permeable water-bearing zones.

The values for coefficient of storage listed in table 3 range from 0.00001 to 0.0003. These values are typical of artesian aquifers whose values for S range from about 0.000001 to 0.001 (Ferris and others, 1962, p. 76). In contrast, the S for water-table aquifers generally falls between 0.01 and 0.30.

The results of the pumping test on well 309-859-1 give values of T and S for the Lockport Dolomite, and also indicate the relative water-transmitting ability of individual water-bearing openings. This test also provides indirect evidence that the Lockport Dolomite, as observed visually in the conduit excavations, consists of relatively impermeable rock within which are a few highly permeable water-bearing openings. Figure 10 shows a section through well 309-859-1 (pumped well) and well 309-859-2 (observation well). As can be seen in the section, both wells penetrate water-bearing zones 1 and 2, and the zone of open joints near the top of rock. The pumping well is known to tap water-bearing zone 3; the observation well may or may not tap zone 3, but is probably hydraulically connected to the zone via joints at the top of rock. Well 309-859-1 was pumped at the rate of 2.2 gpm for 3 1/2 hours. Water-level measurements were made frequently in the observation well and sporadically in the pumped well during the test. A graphical plot

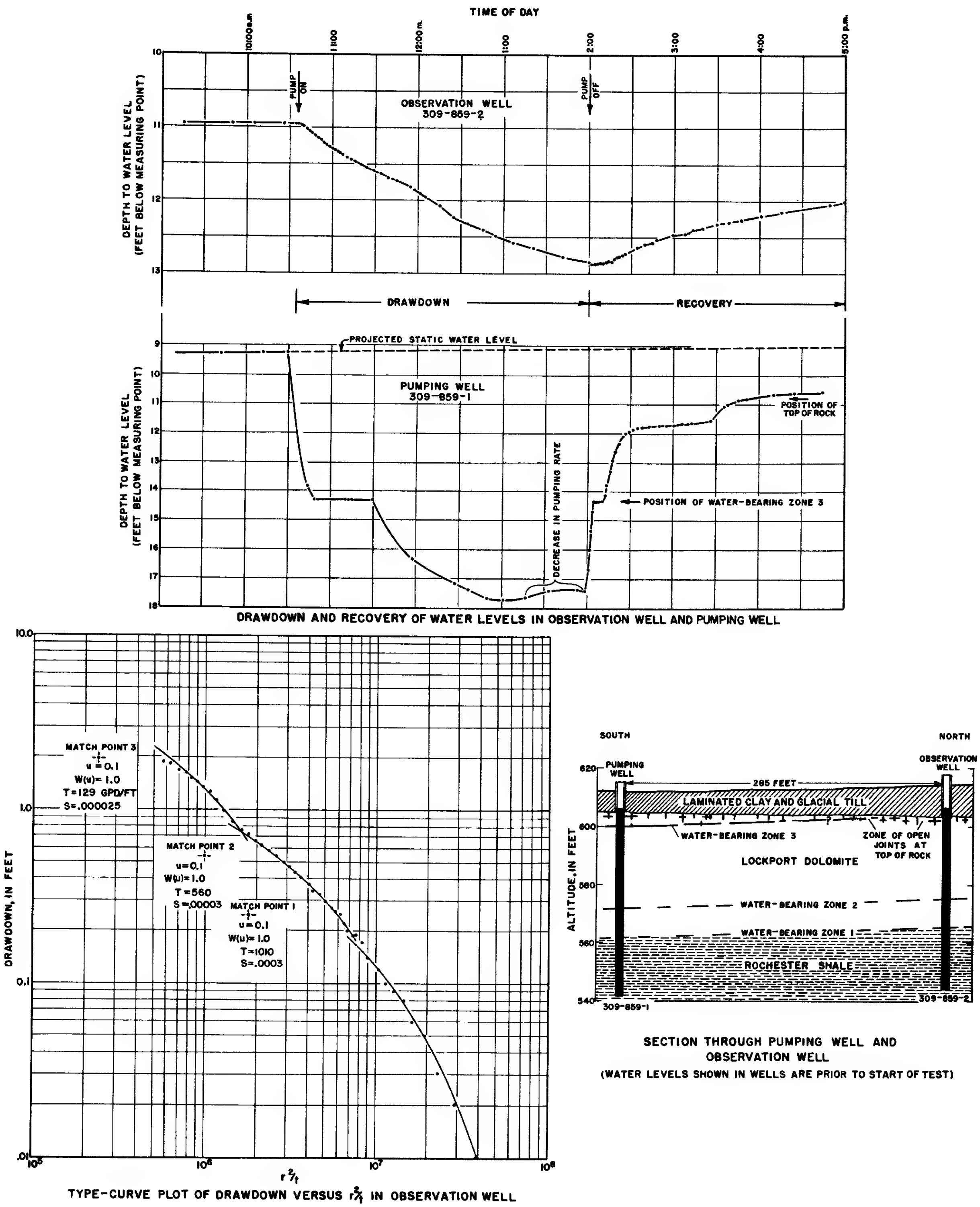


Figure 10.--Pumping test on well 309-859-1, November 4, 1960: Water levels in pumping well and observation well, type-curve plot, and section through wells.

showing the decline and recovery of water levels during the test is shown in figure 10. A log-log plot (Theis method) of drawdown versus $r^2/t$ for the observation well is also shown in the figure.

The degree to which individual water-bearing openings contribute water to the pumped well can be inferred by inspection of the drawdown and recovery curves in the pumped well (fig. 10). The water level in the pumped well dropped 5 feet to the level of water-bearing zone 3 during the first 20 minutes, remained stationary at this level for about 50 minutes, and then abruptly declined 3 more feet where the water level fluctuated until pumping stopped. The initial decline probably represents the time required to dewater the open joints at the top of rock, and the 50-minute interval of stabilization represents the time needed to dewater water-bearing zone 3 near the pumping well. During the last two hours of the test, a large part of the water entering the well apparently came from zones 1 and 2 plus a continuing small amount of seepage from zone 3.

The transmissibility of the Lockport was obtained by analysis of the drawdown curve for the observation well. As a result, the log-log plot of drawdown versus $r^2/t$ (square of distance from observation well to pumping well "r" divided by time since pumping started "t") shows 3 steps (or segments). Analysis of the first segment of the curve (lower right portion) by the Theis method gives a T of 1,000 gpd per foot. This is inferred to be the T of the Lockport with no significant dewatering of the water-bearing openings. The second segment of the curve gives a T of 500 which is believed to be the transmissibility of the formation after dewatering of the jointed zone at top of rock. The third segment of the curve gives a T of 125 which represents the transmissibility after dewatering of water-bearing zone 3. The transmissibility of individual water-bearing openings contributing to the yield of the well is thus broken down as follows:

| | |
|---|---|
| Transmissibility of jointed zone at top of rock | 500 gpd per foot |
| Transmissibility of water-bearing zone 3 | 375 |
| Transmissibility of water-bearing zones 1 and 2 | 125 |
| Transmissibility of total thickness of Lockport Dolomite (38 feet) at well 309-859-2 | 1,000 gpd per foot |

Under idealized conditions the drawdown and recovery curves should be mirror images. However, it is evident from figure 10 that the drawdown and recovery curves of both the observation and pumping wells are not identical. It may be noted that both wells failed to recover to the prepumping level. This was doubtless caused by a lack of recharge from the relatively impermeable glacial till and lake clay overlying the Lockport. Another anomaly is the fact that water-bearing zone 3 at the pumping well required 50 minutes to drain but appears to have been refilled in less than 12 minutes. A possible explanation for this anomaly is that water-bearing zone 3 at the site of the pumping well is largely supplied by vertical joints which are covered at the top of the rock by the relatively impermeable clay or till. The water could not freely drain from these joints during the test until the water level in the pumping well had declined to the level of zone 3. At that point, air could enter the zone to replace the water in the vertical joints. During recovery 12 minutes were required to replace the water in zone 3 to the point where the opening in the zone at the well was submerged. From that point on, the water in the vertical joints could be replaced only as the water level in the well rose.

## Chemical character of the water

Ground water in the Lockport Dolomite is very hard and moderately to highly mineralized. The hardness and mineral content of the water makes it unsatisfactory for many uses without treatment. Chemical analyses of 60 water samples from the Lockport are listed in table 9.

The ground water in the Lockport is typically either a calcium-sulfate or a calcium-bicarbonate water. Figure 11 shows the concentrations of selected constituents in samples of ground water from the Lockport. An analysis of water from the Niagara River is shown for comparison (composite of daily samples collected Oct. 7-15, 18-20, 1958). Typical ground water from the Lockport (shown by thin solid lines) is characterized by high calcium and magnesium, and high sulfate and bicarbonate. These constituents reflect the solution of the host rock, dolomite ($Ca,Mg(CO_3)_2$), and gypsum ($CaSO_4$) by percolating ground water. Although gypsum makes up only a small part of the Lockport it is much more soluble than dolomite and, as a result, most water from the Lockport is characterized by a high sulfate content.

Two types of water which occur in the Lockport differ markedly in composition from the typical Lockport water described above. These waters are in one case much less and in the other case much more mineralized than typical water from the Lockport. The sample from well 304-901-6 (shown by a dashed line in the lower part of figure 11) is an example of the less mineralized type of water. As can be seen in figure 11, the water is intermediate in composition between typical Lockport water and water from the Niagara River (thick solid line). This well is one of several large-yield industrial wells located only a short distance from the Niagara River which are believed to obtain a substantial part of their yield by induced infiltration from the river, as discussed in the previous section.

Examples of the highly mineralized (or saline) water in the Lockport Dolomite are shown by analyses 305-900-1 and 308-901-e in the upper part of figure 11 (dashed lines). These water samples are characterized by much higher concentrations of sodium and chloride than typical water from the Lockport. The saline water samples also contain appreciably higher concentrations of calcium and sulfate than typical Lockport water. Table 9 lists a total of 22 analyses of saline water from the Lockport containing more than 2,000 ppm (parts per million) of dissolved solids. Of these, 16 show more than 500 ppm chloride.

The saline water samples listed in table 9 were collected either from wells known to penetrate the lower two water-bearing zones in the Lockport, or were collected from zones 1 and 2 at the rock face along the conduit excavations. In no case did a water sample from wells penetrating only the upper zones in the Lockport yield saline water. The saline water is thus characteristic of the lower two water-bearing zones. In an attempt to further define the chemical characteristics of water from the lower two zones in the Lockport, water samples were collected from the level of zone 1 in four wells (309-859-1, -2, and -3 and 309-901-7). Sampling was done by lowering a bottle in the wells and opening it at the estimated level of the zone. There are certain drawbacks to this method of sampling, particularly the dilution of water collected at the lower zones by less mineralized water

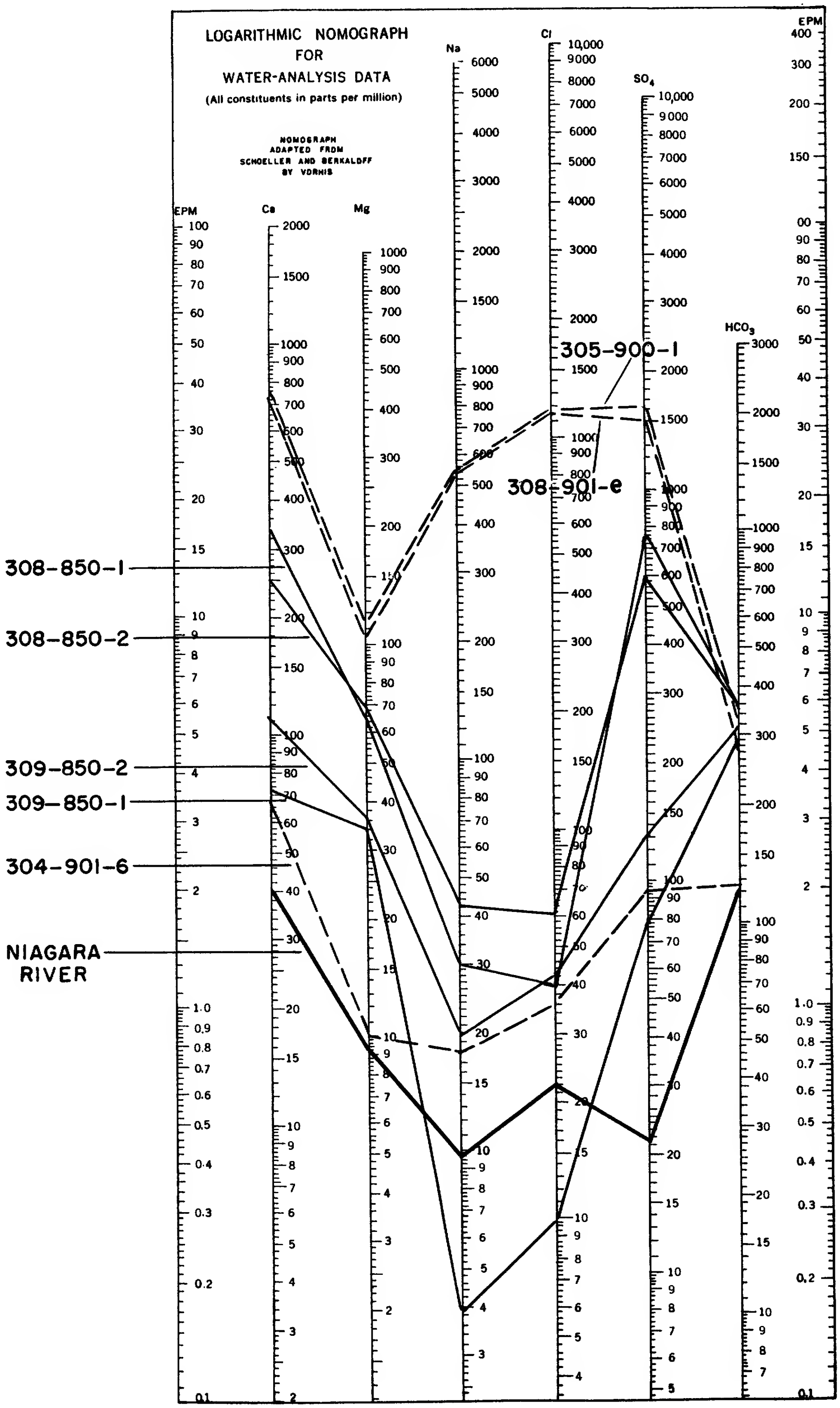


**Figure 11.--Graph showing concentrations of selected chemical constituents in ground water from the Lockport Dolomite and water from the Niagara River.**

moving down from the zones above. However, the results are probably accurate enough to give an indication of the chemical character of the water from zone 1. The chloride content of samples obtained at zone 1 in wells 309-859-3 and 309-901-7 were 700 and 1,170 ppm, respectively. These values compare with chloride contents of 550 and 1,140 ppm for samples 308-902-a and 308-901-e which were collected at zone 1 in the conduit excavations.

Brine [1/] was obtained from water-bearing zone 1 in wells 309-859-1 and -2. The chloride content of the water from zone 1 at wells 309-859-1 and -2 was 123,000 and 11,200 ppm, respectively. These water samples are the most highly mineralized waters collected from bedrock wells in the Niagara Falls area and are similar in chemical composition to many oil-field brines (Levorsen, 1956, p. 310-311). Such highly mineralized water can remain undiluted close to the land surface only if the water is effectively isolated from the zone of circulating ground water. Thus, water-bearing zone 1 in the Lockport at the site of wells 309-859-1 and -2 may be isolated from the remainder of the ground-water reservoir. The geologic structure causing the isolation is not known. Two possible explanations are: (1) water-bearing zone 1 is tightly sealed off in the direction of ground-water movement by a fault, or (2) the brine is contained in a small reef near the base of the Lockport that was penetrated by the well. Faulting of zone 1 on the downdip side of wells 309-859-1 and -2 might provide an effective dam behind which the brine could be trapped. The brine, being more dense than the water normally found in the Lockport, would tend to remain against the fault "dam" rather than flow around it. However, the existence of such a fault trap is highly conjectural because faulting, except for minor displacements of 1 to 2 feet, is not known in the Niagara Falls area. The reef hypothesis assumes that connate water has been trapped inside the reef since the reef formed at the time of deposition of the Lockport, some 300 million years ago. This hypothesis assumes that the reef be bounded on all sides by impermeable rock which effectively sealed the connate water inside. Although small reefs do occur locally in the Lockport, it is probably unlikely that such reefs could be completely isolated from circulating ground water in the Lockport throughout the long interval of time involved.

The chloride content of 60 samples from the Lockport Dolomite listed in table 9 varies from 3 to 123,000 ppm. However, the chloride analyses fall into two distinct groupings; those samples with less than 100 ppm (33 of 60) and those samples with more than 500 ppm chloride (17 of 60). The break between the two groupings of samples further points out the two types of water just discussed. A chloride content of less than 100 ppm is characteristic of the typical Lockport water. Chloride contents of more than 500 ppm are characteristic of the saline water from the zones 1 and 2 in the Lockport as mentioned above. The two brine samples with extremely high chloride contents are local exceptions of unknown origin as explained above. The

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1/ By definition (Krieger, Hatchett, and Poole, 1957, p. 5), a brine has a dissolved-solids content of more than 35,000 ppm. The water samples obtained from water-bearing zone 1 at wells 309-859-1 and -2 show a dissolved-solids content of 198,000 and 21,000 ppm, respectively. For convenience in this report, both are referred to as brine.

chloride content of many shallow wells in the Lockport may be increased by pollution from septic tanks or road salting.

All water in the Lockport Dolomite is characteristically very hard. The range in hardness (excluding the two brine samples) is from 120 to 2,660 ppm and averages 960 ppm. Softening of this water is desirable or necessary before the water can be used for many purposes.

Hydrogen sulfide, locally termed "sulfur water" or "black water," is found in about one-third of the wells in the Lockport. The presence of hydrogen sulfide ($H_2S$) in water is objectionable because it imparts a "rotten egg" odor and taste to the water. Chlorination or aeration is used to remove $H_2S$. No definite areal pattern was ascertained for the occurrence of $H_2S$. In general, deeper wells are more likely to yield water with $H_2S$; however, there are many exceptions.

The dissolved-solids content of water from the Lockport Dolomite (excluding the two brine samples) ranges from 299 to 5,000 ppm and averages 1,400 ppm. These concentrations are higher than those contained in water of most municipal systems. Water having dissolved-solids concentrations greater than 1,000 ppm usually has a detectable mineral taste, but is not necessarily injurious to health.

The chemical quality of the water in the Lockport Dolomite in the area surrounding the pumped-storage reservoir (fig. 3) was investigated to determine if filling the reservoir had changed the chemical quality of the ground water. It was theorized that if the Niagara River water in the reservoir infiltrated into the Lockport it would tend to dilute the more mineralized water in the formation. It was also thought that the increased head in the upper part of the Lockport resulting from infiltration of the reservoir water would tend to decrease the amount of saline water entering a well from the lower zones of the Lockport. To determine if changes in quality did occur, a series of water samples were collected for analysis from four flowing relief wells drilled into the Lockport immediately outside of the reservoir. The dominant chemical constituents in these water samples are listed in table 4.

Two limitations must be considered in interpreting the analyses listed in table 4: (1) the wells were not drilled until after flooding of the reservoir had taken place, thus some slight changes in chemical composition may have already occurred prior to the start of sampling, and (2) the chemical composition of the ground water in the Lockport may vary seasonally, and these variations, if they exist, are not known because sampling was not done for a year prior to flooding. In spite of these limitations, certain consluions may be drawn from the analyses. The following changes in the chemical composition of water in the Lockport near the reservoir took place: (1) there was a slight decrease in the sulfate and dissolved solids content in all four wells, (2) there was no consistent change in chloride content or hardness (well 309-900-9 showed a marked decrease in chloride), and (3) there was a noticeable increase in bicarbonate.

Sulfate is probably one of the most important constituents for indicating the arrival at the wells of the less mineralized water from the reservoir. However, the decrease in the sulfate content observed in all

Table 4.--Chemical analyses of ground water from flowing wells in the Lockport Dolomite near the pumped-storage reservoir

| Well number | Date sampled | Bicarbonate ($HCO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Calcium, magnesium hardness (as $CaCO_3$) | Dissolved solids |
|---|---|---|---|---|---|---|
| 308-900-16 | 4/13/62 | 318 | 1,120 | 65 | 1,410 | 2,200 |
| | 5/14/62 | 320 | 1,070 | 58 | 1,380 | 2,130 |
| | 7/ 6/62 | 320 | 1,060 | 54 | 1,500 | 2,090 |
| | 11/14/62 | 364 | 1,030 | 50 | 1,500 | 2,010 |
| 309-858-3 | 4/13/62 | 200 | 318 | 91 | 535 | 896 |
| | 5/14/62 | 188 | 305 | 104 | 528 | 875 |
| | 7/ 6/62 | 237 | 315 | 120 | 570 | 883 |
| | 11/14/62 | 320 | 262 | 120 | 578 | 805 |
| 309-858-4 | 4/13/62 | 162 | 277 | 48 | 443 | 687 |
| | 5/14/62 | 141 | 250 | 41 | 387 | 640 |
| | 7/ 6/62 | 154 | 210 | 40 | 380 | 562 |
| | 11/14/62 | 228 | 156 | 48 | 350 | 457 |
| 309-900-9 | 4/13/62 | 365 | 1,300 | 590 | 1,860 | 3,490 |
| | 5/14/62 | 396 | 1,380 | 790 | 2,100 | 3,900 |
| | 7/ 9/62 | 409 | 1,260 | 670 | 1,990 | 3,560 |
| | 11/14/62 | 424 | 1,260 | 148 | 1,620 | 2,360 |

four wells listed in table 4 is probably not of sufficient magnitude (except possibly in well 309-858-4) to clearly indicate the arrival of river water at the wells. The chloride content of the water is probably not as reliable an indicator of a change in chemical quality as the sulfate content because the chloride content is more subject to variation resulting from manmade causes such as road salting and pollution from septic tanks. Thus, small changes in chloride content may be the result of manmade activities rather than movement of water from the reservoir. A sharp decline in chloride content, however, such as that observed at well 309-900-9, may reflect the effect of the reservoir. The high chloride content originally observed in the well probably was caused by saline water moving up the well from the lower water-bearing zones in the Lockport. The sharp decline in chloride content may reflect either (1) the increased head in the upper part of the Lockport which greatly reduced the amount of saline water entering the well from lower zones or (2) the arrival at the well of "fresher" water from the reservoir.

The increase in bicarbonate content may at first appear anomalous. However, such an increase is, in fact, to be expected as a result of reservoir flooding. The water from the reservoir contains approximately 125 ppm bicarbonate. (See analysis of Niagara River water in figure 11.) In contrast, rain water, which is the normal source of recharge to the Lockport Dolomite, contains much less bicarbonate, possibly only a few parts per

million. However, the ability of the reservoir water to dissolve dolomite, and thus to increase its bicarbonate content, is roughly equal to the dissolving ability of rain water. This results from the fact that the ability of water to dissolve dolomite and limestone is largely dependent upon its carbon-dioxide content which is roughly equal in both rain water and the reservoir water. Because of this, water infiltrating into the Lockport from the reservoir has a "headstart" of 125 ppm bicarbonate. Therefore, an increase in bicarbonate content, such as that observed in the four wells listed in the preceding table, may represent the arrival at the wells of water from the reservoir.

## CLINTON AND ALBION GROUPS

The Clinton and Albion Groups are a series of shales, sandstones, and limestones which crop out along a narrow belt parallel to the Niagara escarpment. The Clinton rocks are composed principally of the dark-gray Rochester Shale, but also contain two thin limestones and a thin shale unit. The Albion Group consists of two thin sandstones which are separated by a sequence of alternating shale and sandstone. The names and distinguishing lithologic features of the formations making up the Clinton and Albion Groups are given in figure 5.

The Clinton and Albion Groups are little utilized as sources of ground water, mainly because they are overlain everywhere, except along the Niagara escarpment, by the more productive Lockport Dolomite. Accordingly, not much is known about their water-bearing properties. In general, the limestones and sandstones are the most permeable units in the Clinton and Albion Groups. The abundance of both vertical and bedding joints in outcrops and quarries in the limestones and sandstones suggests that they are as permeable as the Lockport. However, the position of the relatively impermeable Rochester Shale at the top of the Clinton Group drastically limits recharge to the more permeable sandstones and limestones below. As a result the uppermost part of the more permeable limestone units in the Clinton Group is dry in many places. Because of the lack of recharge, the average yield of wells in the Clinton and Albion Groups is only 2 to 3 gpm which is adequate only for small domestic and farm supplies.

The water in the Clinton and Albion rocks is highly mineralized and very hard. As shown in table 2, the average hardness and chloride content of water from the Clinton and Albion Groups is the highest in the Niagara Falls area.

## QUEENSTON SHALE

The Queenston Shale consists mostly of brick-red, sandy shale and thin beds of greenish-gray shale and greenish-gray sandstone. The thickness of the Queenston is 1,200 feet. However, only 200 feet are exposed in the area; the remainder of the formation crops out under Lake Ontario.

## Water-bearing characteristics

Ground water occurs principally within a fractured and weathered zone at the top of the shale. This zone, according to drillers, is generally less than one foot thick. The unweathered Queenston Shale is less permeable than the overlying rocks in the Clinton and Albion Groups and much less permeable than the Lockport Dolomite.

Information obtained from wells drilled into the Queenston Shale, particularly data on yields, usually gives a misleading impression of the water-bearing properties of the formation. In general, the reported yields are too high because most wells penetrating the Queenston draw water from both the Queenston and the overlying unconsolidated deposits. This results from the fact that well drillers in the area commonly end the casing of wells a short distance above the top of the Queenston. Thus, a well in the Queenston with a reported yield of 10 gpm may derive 5 gpm from the unconsolidated deposits, 4 3/4 gpm from the weathered and fractured part of the Queenston, and 1/4 gpm from the unweathered part. The average of the reported yield of the wells drawing from the Queenston Shale listed in table 7 is 7 gpm. This average does not include some domestic and farm wells also listed in the table which have been abandoned for lack of adequate yields. The average yield of wells penetrating the Queenston, which are known also to penetrate a gravelly zone immediately above the Queenston, is 19 gpm.

Considerable difficulty is experienced in developing adequate water supplies in areas where the fractured zone at the top of the Queenston is dry. Such is the case near the village of Newfane, where the Queenston is overlain by less than 10 feet of surficial deposits and the water table lies below the top of rock. Well 316-843-2, a 6-inch-diameter drilled well located in this area, is inadequate to supply one family. Depth to rock at the well is 8 feet and the static water level is 16 feet below land surface (8 feet below the top of the rock). Well 316-843-1, a 48-inch-diameter dug well located about 100 feet to the east of well -2, also has a static water level 16 feet below land surface and is barely adequate to supply one family. In this area, where the fractured zone at the top of the Queenston is dry, the relatively small amount of water needed by one family can be obtained only through the use of a large-diameter well.

## Chemical character of the water

Ground water in the Queenston Shale is very hard and locally is highly mineralized. The water is generally not satisfactory for most uses without treatment. The average dissolved-solids content of water in the Queenston is 2,600 ppm and ranges from 533 to 8,920 ppm. As shown in table 2, the hardness of water samples from the Queenston ranges from 219 to 1,910 ppm and averages 883 ppm. Softening of such water is desirable for many uses.

The chloride concentration of water from the Queenston Shale ranges from 90 to 3,150 ppm, the average being 646 ppm (table 2). Water containing more than 500 ppm chloride is salty to the taste. Wells yielding salty

water from the Queenston are usually found in two areas--(1) in a band about two miles wide immediately north of the Niagara escarpment, and (2) in areas immediately adjacent to streams. Both these areas are believed to be places of ground-water discharge--that is, areas where ground water is moving upward from the Queenston to discharge naturally.

The origin of the salty water in the Queenston is unknown. In commenting on a similar occurrence of salty water in the bedrock in northern St. Lawrence County, N. Y., Trainer and Salvas (1962, p. 103) suggest three causes for the salty water in that area: (1) connate water, (2) the Champlain Sea, and (3) evaporite deposits. They conclude that the Champlain Sea, which covered the area about 10 or 20 thousand years ago, is the most likely source. This source is not applicable to the Niagara area, however, because the Champlain Sea did not extend into the area. Furthermore, it is unlikely that the salty water in the Niagara area is derived from evaporite beds because no such deposits are known to exist in the Queenston. Nor do any salt beds occur in the bedrock formations overlying the Queenston Shale (fig. 5) in the Niagara Falls area. The nearest salt beds occur about 40 miles to the southeast in the Salina Group which overlies the Lockport Dolomite. However, it is very improbable that salty water from the Salina beds has entered the Queenston Shale because (1) the salt beds themselves act as impermeable barriers to water moving downward from the Salina to the Queenston, and (2) it is more likely that salty water from the Salina would be discharged at points between the outcrop areas of the two formations.

Although direct evidence is lacking, the writer believes that the salty water in the Queenston Shale is most likely derived from connate water. The discharge of connate water begins as soon as a deeply buried bed is brought up into the zone of circulating ground water. The Queenston rocks were deposited as a sea-bottom clay about 350 million years ago, and have been deeply buried throughout most of the intervening time. During some thousands of years of Recent geologic time, connate water has been flushed from the upper several hundred feet of the Queenston. However, it is probable that flushing of the deeper part of the formation is continuing at present.

## OCCURRENCE OF WATER IN UNCONSOLIDATED DEPOSITS

The unconsolidated deposits in the Niagara Falls area are not important sources of water. These deposits may be classified into two types based on their water-bearing properties: (1) coarse-grained materials of high permeability (sand and gravel), and (2) fine-grained materials of very low permeability (glacial till and lake deposits). The unconsolidated deposits in the Niagara Falls area are predominantly of the fine-grained type. However, the lack of sand and gravel deposits in the Niagara Falls area, other than a few deposits of very limited thickness and extent, has severely limited the development of large ground-water supplies in the area. Most large ground-water supplies in New York State are derived from sand and gravel deposits.

Table 2 shows selected chemical constituents from wells tapping unconsolidated deposits. Water from the different types of unconsolidated deposits is not easy to differentiate on the basis of quality because many

wells tap more than one type of deposit. Thus, water samples from such wells are mixtures of water from two or more deposits. In general, water from the unconsolidated deposits is very hard, but not so highly mineralized as water from the bedrock. A complete analysis of water from well 312-859-1, which taps both till and lake deposits, is listed in table 9. This is a calcium bicarbonate water, very hard (568 ppm of total hardness) containing a moderately high chloride content (105 ppm). Water from the unconsolidated deposits generally has a wide range in chloride content. Those wells which yield water with a high chloride content are probably affected either by (1) local pollution, or by (2) upward discharge of saline water from the underlying bedrock.

## SAND AND GRAVEL

Sand and gravel is found in small isolated hills and in a narrow "beach ridge" which crosses the area along an east-west line (pl. 3). The sand and gravel deposits are of limited areal extent, generally thin, and occur as topographic highs. The deposits commonly consist of two lithologic types: (1) fine-grained reddish-brown sand, and (2) coarse sand and pebbles with a matrix of fine to medium sand. The origin of both the beach ridge and small hills of sand and gravel is associated with glaciation in the Niagara Falls area. The small hills are kames, i.e. hills of sand and gravel formed originally against an ice front by deposition from sediment-laden melt-water streams. The long, narrow beach ridge is believed to represent a former shore line of glacial Lake Iroquois. This large lake, the predecessor of the present Lake Ontario, existed in the Niagara Falls area near the end of the Ice Age. The sand and gravel composing the beach ridge apparently was produced from pre-existing material by wave action at the shore which winnowed out most of the silt and clay originally contained in the glacial deposit.

Although the sand and gravel deposits in the Niagara Falls area are much more permeable than the other unconsolidated deposits or the bedrock, their occurrence as small topographic highs permits them to drain rapidly. As a result, ground water generally occurs only within a thin zone at the base of the sand and gravel. This is shown in the cross section of the beach ridge in figure 12. It can be seen that the water table is only a few feet above the base of the sand and gravel. Extensive pumping of any of the wells shown would quickly dewater the sand and gravel. In general, wells in the beach ridge and kames will yield only the small amounts of water required for domestic and small-farm needs.

Moderate supplies of ground water can be obtained from a sand and gravel deposit (probably a kame) just east of Lockport, N. Y. (pl. 3). This is the largest sand and gravel deposit in the area, measuring 1 1/2 by 3/4 miles in size. The thickness of the deposit is highly variable because of the hummocky nature of the land surface, but probably averages 60-70 feet. Some notion of the ability of this deposit to yield water is shown by the yield of 165 gpm pumped from a sand pit during excavation. One large-diameter supply well has been constructed in this deposit. This well (311-838-3) was reportedly pumped at a rate of 200 gpm for 24 hours in 1956.

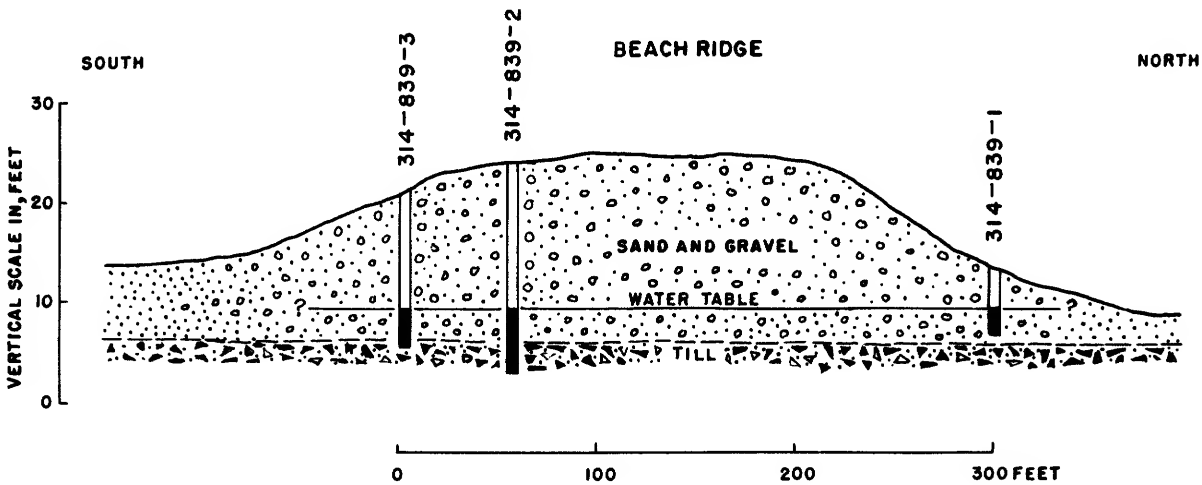


Figure 12.--Cross section of sand and gravel "beach ridge" through wells 314-839-1, -2, and -3.

## LAKE DEPOSITS

Lake deposits consisting of silt, clay, and fine sand occur throughout the Niagara Falls area. These deposits are predominantly composed of laminated silt and clay which is characteristically dense and compact. Thin beds of fine sand (locally called quicksand) occur in the lake deposits. The clay, silt, and sand were deposited in lakes which existed in the area at the close of the Pleistocene Epoch (10,000 to 15,000 years ago). The lakes, which formed in the wake of the melting ice sheet, provided large bodies of quiet water for the slow accumulation of fine-grained deposits. Thus, the lake deposits are found at the surface nearly everywhere in the Niagara Falls area. The deposits are thinnest in the area south of the Niagara escarpment where they rarely exceed 20 feet in thickness. On the lake plain north of the escarpment the deposits average 30 to 40 feet in thickness; however, locally they vary from 0 to 90 feet in thickness. The greater thickness on the lake plain results from the persistence of a lake in this area (glacial Lake Iroquois) after the area south of the escarpment was above water.

The silt and clay have extremely low permeability and yield little water to wells. The thin beds of fine sand have comparatively greater permeability. Wells which tap only clay and silt will yield less than 100 gpd; those wells tapping sand beds yield more water and are usually adequate for domestic or very small agricultural needs. The lake deposits are utilized for water supplies only in the lake plain (north of the Niagara escarpment); to the south of the escarpment the deposits are too thin and are underlain by the much more permeable Lockport Dolomite.

The impermeable nature of the silt and clay was shown by a recovery test conducted on well 315-859-1. This well is believed to penetrate only clay and silt. After being pumped dry, the well required 4 1/2 months for

the water level to rise to its static level 13 feet above the bottom. The permeability of the clay and silt, as calculated from the recovery data, was 0.04 gallons per day per square foot. The well was originally intended to provide water for a domestic supply, but was inadequate. In contrast, well 315-859-2, which is located about 500 feet to the south, provides an adequate domestic supply. This well undoubtedly penetrates a thin bed of sand.

## GLACIAL TILL

A thin veneer of glacial till lies between the lake deposits described above and the bedrock throughout nearly all of the Niagara Falls area. The till is a mixture containing mostly sandy silt with boulders, pebbles, and some clay. The till was deposited directly by the ice sheet and is composed of rock which was quarried by the advancing ice, then ground up, and "plastered down" beneath the ice. The till cover in the Niagara Falls area is generally less than 10 feet thick. The greatest thickness of till (30 to 40 feet) is found in the moraines in the eastern part of the area. These features are the low ridges which trend approximately east-west located in the area southeast of Lockport and south of Medina (pl. 3). The moraines are composed of debris which was piled up in front of the advancing ice front. The moraines in the Niagara Falls area are believed to represent four minor readvances of the ice sheet during its retreat from the area (Kindle and Taylor, 1913, p. 10).

The poorly sorted nature of the till causes it to have very low permeability. An indication of the low permeability was obtained from a "slug" test on well 309-900-8. This well penetrates 7.5 feet of lake clay and silt and 1.5 feet of glacial till, and is cased through the lake deposits. The permeability of the till at this well was determined to be 23 gallons per day per square foot. This value for permeability may be too high because the well bottomed at the top of the Lockport Dolomite. Thus an open joint in the rock could have contributed to the yield of the well. However, the value for permeability may be representative of the "washed till-top of rock" aquifer tapped by many dug wells in the Niagara Falls area.

Yields adequate for domestic needs are obtained from till wells which tap: (1) sand lenses within the till, (2) the relatively permeable ("washed") zone at the top of rock, or (3) the sandy till making up the moraines. Wells which do not tap these more permeable horizons in the till are often inadequate to supply even domestic needs. Such inadequate wells yield less than 100 gpd.

# . . . GROUND-WATER HYDROLOGY

## HYDROLOGIC CYCLE

The hydrologic cycle is the series of events through which water passes from water vapor in the atmosphere to precipitation, to runoff on the land surface and infiltration into the ground, and finally back into the atmosphere again via evaporation from land and water surfaces and transpiration by vegetation. A schematic representation of the hydrologic cycle in the Niagara Falls area is shown in figure 13.

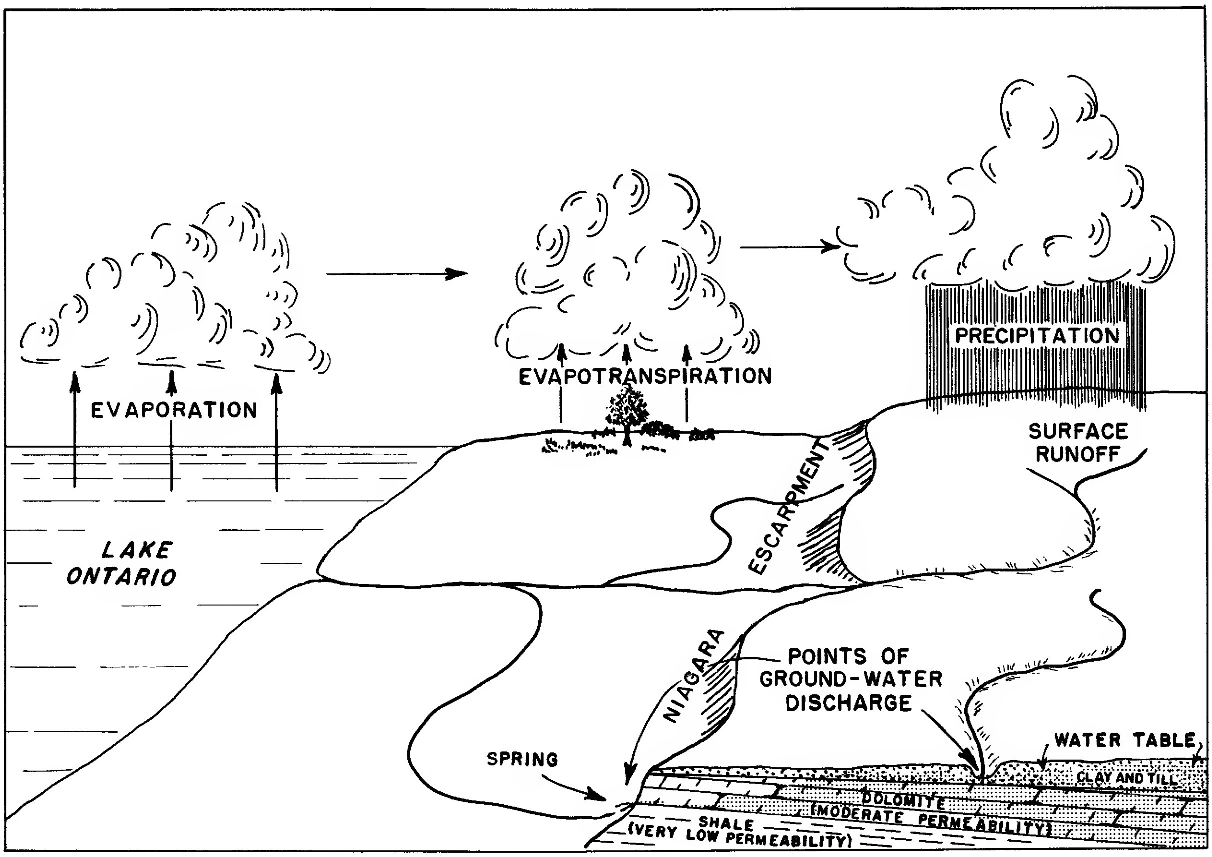


Figure 13.--Schematic representation of the hydrologic cycle in the Niagara Falls area.

Precipitation is the source of all ground water and surface water in the area. A small part of the precipitation in the area is derived from evaporation from Lake Ontario and the other Great Lakes. Much of the

remainder is derived from evaporation from the Gulf of Mexico. Water reaching the surface as rain or snow either runs off via streams or enters the soil. Some of the water is returned to the atmosphere by evaporation from the surface and by transpiration from plants. Some of the water entering the soil is held by capillary attraction against the force of gravity. Such water is termed soil moisture. Additions to soil moisture are made by rainfall and melting snow, whereas withdrawals are made through evaporation or absorption by plant roots.

When the force of gravity exceeds the capillary pull, water moves downward through the soil. The rate of downward movement (infiltration) depends upon the vertical permeability of the soil. The permeability is highest in coarse-grained materials and lowest in fine-grained materials. As a result, infiltration of water into a coarse soil such as a sandy loam is much more rapid than in a very fine-grained soil such as a clay loam. Upon reaching the water table, the water becomes ground water and continues its movement, laterally and downward under the pull of gravity, until it eventually discharges at the land surface. The movement of ground water from points of recharge to points of discharge will be discussed further in a later section. Points of ground water discharge in the Niagara Falls area include the springs emanating from the Lockport Dolomite along the Niagara escarpment and the beds of streams (fig. 13).

During fair weather, after storm runoff has passed downstream, the flow of streams is dependent wholly upon ground-water discharge, called base flow. Most small streams in the Niagara Falls area are dry for a few months each year because ground-water discharge (at the land surface or in a stream bed) is insufficient to maintain stream flow. This is particularly true on the lake plain north of the escarpment because the deposits there (silt and clay on shale) have very low permeability and, therefore, contribute insufficient ground water to the streams to maintain flow during the dry months.

The streams draining the Niagara Falls area discharge into Lake Ontario either directly or via the Niagara River and evaporation from the lake then begins the cycle again. Water which circulates through the deeper parts of the bedrock often requires hundreds of years to complete the hydrologic cycle, whereas water which evaporates from the soil may need only hours. Thus, the time required to complete the cycle varies from hours to hundreds of years.

## CLIMATE

The climate of the Niagara Falls area is the humid continental type. It is subject to less extremes in temperature than most of upstate New York because of its nearness to Lake Ontario and Lake Erie, and it is also notable for having the smallest annual precipitation in the State. These climatic characteristics are a product of the location of the area adjacent to the Great Lakes and of its flat topography.

The small annual precipitation is due to the position of the area with respect to Lakes Ontario and Erie, and to the low relief in the area. The prevailing westerly winds enter the area mainly via the narrow strip of land

separating Lake Erie from Lake Ontario. The winds are thus less moisture-laden than if they had passed over the lakes. Even those winds which may be moisture-laden (from evaporated lake water) may retain most of their moisture until they reach the more hilly areas east of Lake Ontario. The Niagara escarpment appears to have a local effect on the amount of precipitation also. As can be seen from the precipitation data given in table 5, Lewiston (elevation 320 feet), which is located below the escarpment, receives less precipitation than Lockport (elevation 520 feet), which is at the escarpment. Table 5 also shows that precipitation is fairly evenly distributed throughout the year. Within a given year, however, large variations from the average figures listed may occur. Note that the minimum monthly precipitation for each month during the 25-year period is between 1/2 and 1/20 the average precipitation for that month. However, the minimum annual precipitation (1941) is more than 1/2 the average annual precipitation. Average annual temperature is 48°F at Lewiston. The length of the growing season averages 160 days.

# GROUND WATER

A part of the rain and snow falling on the Niagara Falls area seeps into the ground and continues downward to the water table to become ground water. The ground water is in constant, but generally very slow, movement from points of recharge to points of discharge. Ultimately all ground water in the area is discharged into Lake Ontario or the Niagara River either directly or via small tributary streams. The Niagara Falls area is, in effect, a peninsula-shaped catchment area in which the ground-water reservoir is being repeatedly replenished by precipitation, and constantly discharging to the surrounding surface-water bodies. This section of the report describes: (1) recharge to the unconsolidated deposits and the bedrock, (2) movement and discharge of ground water in the area, and (3) changes in storage in the ground-water reservoir as shown by water-level fluctuations.

## RECHARGE

The source of nearly all the ground-water recharge in the Niagara Falls area is precipitation; however, a small amount of recharge also occurs in the area beneath and immediately adjacent to the Niagara Power Project reservoir by infiltration from the reservoir. Recharge of ground water means simply the addition of water (or quantity added) to the zone of saturation (Meinzer, 1923, p. 46). The rate and amount of recharge depends mainly upon the permeability of the soil, the amount of precipitation, and the soil-moisture condition at the time of precipitation. The rate of infiltration of water into the soil increases with increase of permeability. In the relatively small part of the Niagara Falls area underlain by sand and gravel, infiltration rates are greatest. However, throughout most of the area underlain by glacial till and lake clays and silts infiltration rates are low and surface runoff is high.

Table 5.--Monthly precipitation at Lewiston and Lockport, N. Y., 1936-60
(Data from reports of U.S. Weather Bureau)

| Month | Lewiston (1 mile north of; elevation 320 feet) | | Lockport (2 miles northeast of; elevation 520 feet) | |
|---|---|---|---|---|
| | Average (inches) | Minimum (inches) | Average (inches) | Minimum (inches) |
| January | 1.98 | 0.59 (1946) | 2.38 | 0.67 (1946) |
| February | 2.35 | .54 (1947) | 2.52 | .85 (1947) |
| March | 2.49 | .63 (1958) | 2.56 | .71 (1958) |
| April | 2.66 | .83 (1946) | 2.80 | .91 (1946) |
| May | 3.08 | .71 (1941) | 3.26 | .94 (1936) |
| June | 2.18 | .66 (1953) | 2.41 | .33 (1953) |
| July | 2.44 | 1.15 (1955) | 2.70 | .90 (1954) |
| August | 2.57 | .21 (1948) | 2.97 | .36 (1948) |
| September | 2.97 | .46 (1941) | 2.92 | .14 (1941) |
| October | 2.55 | .47 (1947) | 2.85 | .60 (1938) |
| November | 2.33 | .75 (1939) | 2.62 | .64 (1939) |
| December | 2.02 | .39 (1958) | 2.39 | .71 (1943) |
| Annual | 29.62 | 17.64 (1941) | 32.38 | 19.75 (1941) |

The mechanism of recharge to the Lockport Dolomite is of primary concern in this report because this bedrock unit is by far the most important aquifer in the Niagara Falls area. As discussed previously, most ground water occurs in the Lockport within seven relatively permeable zones parallel to bedding which are separated by essentially impermeable rock. Recharge to these water-bearing zones occurs by one of two mechanisms: (1) downward movement of water through vertical joints or (2) recharge directly to the water-bearing zones at the outcrop of the bedding joints composing the zones.

Several lines of evidence suggest that recharge to the Lockport Dolomite occurs predominantly at the outcrop of the water-bearing zones. The lack of persistent open vertical joints in the Lockport as observed in the conduit

excavations, suggests that vertical joints are not important avenues for downward movement of water. However, this is not conclusive evidence in itself because on an areal basis, many vertical joints, although apparently tight, might be able to transmit appreciable quantities of water when considered as a whole even though each joint singly might transmit a very small quantity of water. More conclusive evidence of a negligible movement of water along vertical joints is the occurrence of "dry" open bedding joints below the "wet" bedding joints comprising the water-bearing zones in the Lockport (fig. 8). This phenomenon could not occur if permeable vertical joints connected the "dry" and "wet" bedding joints. It seems probable that the "dry" bedding joints exist because they receive little or no recharge in their outcrop area. This lack of recharge would be particularly applicable to those bedding joints cropping out along the Niagara escarpment where there is very little opportunity for recharge.

The most important indication that recharge to the water-bearing zones of the Lockport Dolomite occurs at the outcrop of the zones, is the alignment of water levels approximately parallel to the dip of the zones themselves. This alignment of water level is shown for water-bearing zone 3 in figure 9.

The wells shown in the cross section are adjacent to the reservoir of the Niagara Power Project; however, the water levels shown were measured prior to flooding of the reservoir. If recharge to the water-bearing zones did occur throughout the area by downward movement through vertical joints, the gradient along the zones would steepen in the downdip direction rather than continue roughly parallel to the dip of the zones--that is, if it is assumed that there is no increase in transmissibility downdip. This steepening of the hydraulic gradient would be required in order to transmit the ever-increasing amounts of water supplied to the zone by the vertical joints. No such steepening of the gradient was observed.

In summary, it appears that recharge occurs principally at the outcrop of the water-bearing zones in the Lockport Dolomite and that water then moves down the dip of the zone with a relatively constant loss of head. Recharge is probably not limited to the actual line of outcrop of a zone, however, but occurs throughout the area where the zone is reached by the enlarged vertical joints that occur in the upper few feet of the rock.

Little is known about the recharge to the other bedrock formations underlying the Niagara Falls area. It is probable that a very small amount of water moves downward from the Lockport Dolomite into the Rochester Shale and the underlying bedrock units. As was pointed out in the preceding discussion, however, vertical openings even in the Lockport Dolomite appear to transmit relatively little water except in the upper few feet of the rock. Therefore, movement of water from the Lockport into the underlying formations probably occurs only along widely spaced major vertical joints. Some of the water in the deeper bedrock units in the Niagara Falls area may also be derived from recharge to these beds in the area to the south. Such water would move through the Niagara area toward the Niagara gorge and Lake Ontario, both of which are regional discharge areas.

## GROUND-WATER MOVEMENT AND DISCHARGE

Ground water moves from points of high head to points of low head (or potential), in other words from points where the water table or piezometric surfaces are highest to points where they are lowest. The direction of ground-water movement in the upper few feet of bedrock and in the unconsolidated deposits (where water-table conditions exist) is shown by the configuration of the water table. The direction of movement in the remainder of the bedrock is shown by the configuration of the piezometric surfaces associated with each of the artesian water-bearing zones in the different bedrock formations.

As discussed previously, each of the seven water-bearing zones in the Lockport is a distinct artesian aquifer with an associated piezometric surface. To show in detail the ground-water movement in the Niagara Falls area, it would be necessary to construct a water-table map, and piezometric maps for each of the water-bearing zones. Such maps are not included in this report because water levels could be measured in relatively few wells and because of the difficulty of differentiating between water levels which represent the water table and water levels which represent the piezometric surfaces associated with each of the several water-bearing zones. In a few wells constructed with packers, such as shown in figure 9, it was possible to measure separate water levels associated with the water table and with distinct water-bearing zones. In wells not equipped with packers, which includes all domestic and industrial wells in the area, a measured water level is an average of the heads of the different water-bearing openings penetrated by the well. Such an average water level represents neither the water table nor the piezometric surface of a single water-bearing zone.

Nearly all water-level data that could be used in determining direction of ground-water movement were obtained from wells in the vicinity of the pumped-storage reservoir. These data show that in general the configuration of the water table follows the surface of the land, being highest under hills and in interstream tracts and lowest in stream valleys. The configuration of the piezometric surfaces associated with each water-bearing zone in the Lockport has little relationship to the land surface. The piezometric surfaces are approximately parallel to the slope of the water-bearing zones. The disparity in the configuration of the water table and the piezometric surfaces is shown in figure 9, which was previously referred to in the discussion of artesian and water-table conditions in the Lockport. As shown in the figure, the water table slopes from all directions toward Fish Creek, whereas the piezometric surface for water-bearing zone 3 slopes to the south away from the creek. Thus, ground-water movement in the upper fractured part of rock and in the overlying unconsolidated deposits is toward the creek, but movement along water-bearing zone 3 and, presumable in the other water-bearing zones, is to the south toward the upper Niagara River.

Figure 14 shows the inferred direction of ground-water movement in the upper water-bearing zones of the Lockport Dolomite. This figure is based on adequate data only in the vicinity of the reservoir. Because only a few scattered water-level observations are available for the area south of the reservoir, the flow lines in that area are based largely on the fundamental principles governing ground-water movement.

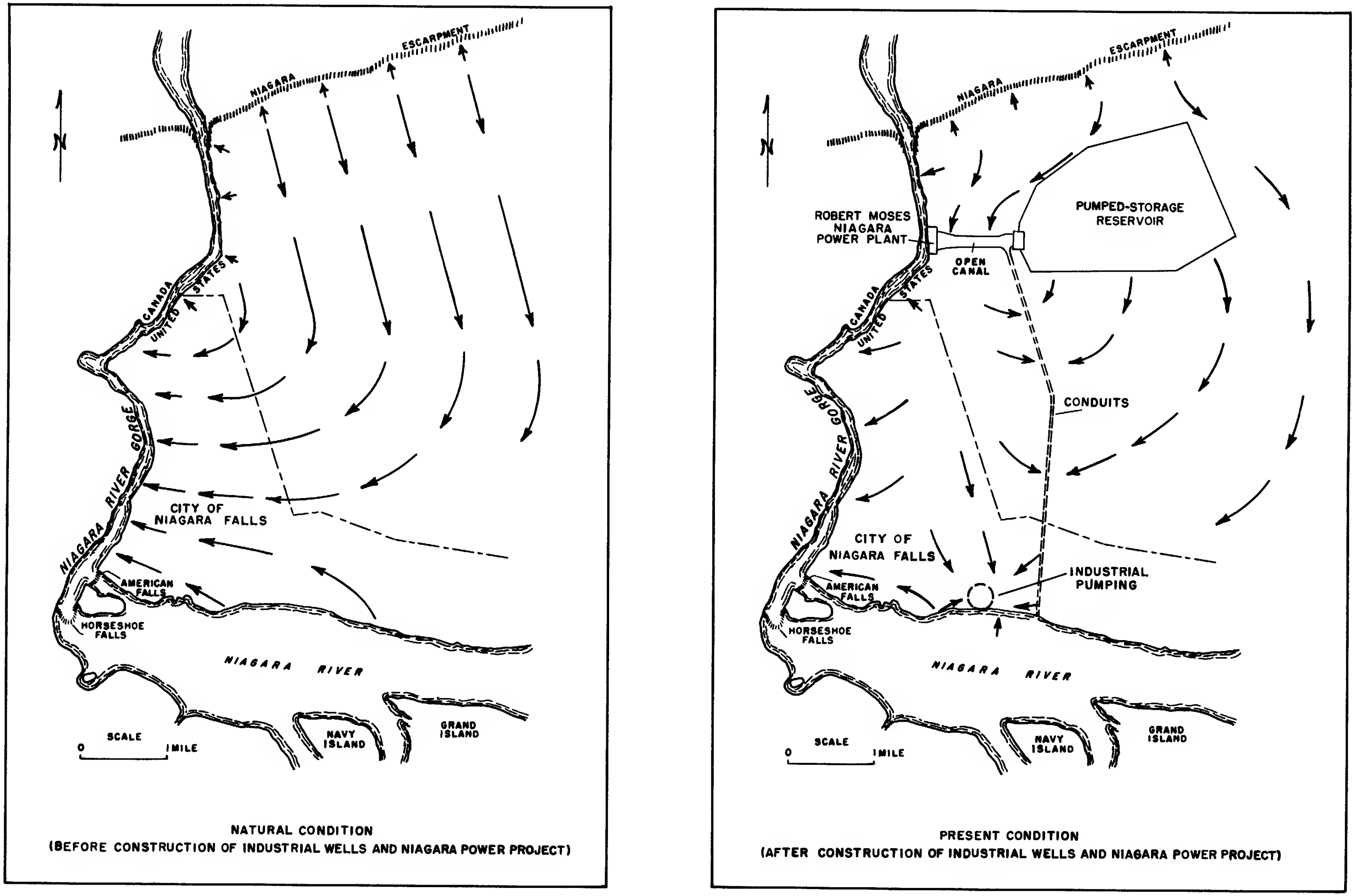


Figure 14.--Inferred direction of ground-water movement in the upper water-bearing zones of the Lockport Dolomite in the vicinity of Niagara Falls.

It may be observed in figure 14 that ground water in the Lockport Dolomite moves north toward the Niagara escarpment in a narrow area parallel to the escarpment. This northerly direction of ground-water movement is shown by (1) the location of springs near the base of the Lockport along the escarpment (pl. 1), and (2) the decline of water levels in wells in the direction of the escarpment. A divide in the water table and in the upper fractured part of the rock apparently exists at a distance of 1,000 to 2,000 feet south of the escarpment. The existence of this divide is shown by the reversal of hydraulic gradient in the area. The gradient is toward the escarpment in the area less than 1,000 feet south of the escarpment. However, a hydraulic gradient to the southeast (approximately parallel to the dip of the beds in the Lockport) was observed in wells located over 2,500 feet south of the escarpment.

Prior to the start of the investigation it was assumed that water in the Lockport Dolomite in the western part of the Niagara Falls area moved west to the gorge to discharge. It was observed very early in the study, however, that there was practically no evidence of seepage on the sides of the gorge. The lack of seepage could be explained by (1) assuming that the water moving toward the gorge was intercepted by enlarged vertical joints parallel to the gorge, or (2) assuming that there was little or no movement of water toward the gorge.

Because the city of Niagara Falls and the area along the gorge north of the city is supplied by the Niagara Falls municipal water system, very few wells suitable for water-level observations were found in the area. The only wells readily accessible for water-level measurements were in the vicinity of the power station and canal. The data from these wells indicate that water moves toward the gorge. The width of the area supplying water to the gorge, however, could not be determined. Indirect information relative to this problem was derived from the water-level measurements in the vicinity of the reservoir. It was found that if the slope of the piezometric surface for a specific water-bearing zone (for example, zone 3 in figure 9) was extended to the south, the pressure reached the level of the upper Niagara River a short distance south of the reservoir. This does not prove but certainly strongly suggests that under natural (pre-power project) conditions the water in the Lockport Dolomite turned west to discharge into the Niagara River gorge, roughly midway between the escarpment and the upper Niagara River (fig. 14). The absence of seepage on the sides of the gorge, therefore, is believed to be attributable to enlarged vertical joints parallel to the gorge.

Ground-water movement as it probably existed in 1962 may be summarized as follows: (1) water moves northward in a narrow area parallel to the Niagara escarpment, (2) water moves southward (downdip) in the area around the reservoir (which acts as a recharge mound and tends to deflect the water moving from the north), (3) water moves into the canal, conduits, and area of industrial pumping to discharge, and (4) water moves toward the gorge in the southwestern part of the area.

On the lake plain, north of the Niagara escarpment, ground water moves in a generally northward direction toward Lake Ontario. The water table is located within the lake deposits about 3 to 10 feet below the surface. The

water table very nearly parallels the land surface and slopes regionally toward Lake Ontario with a gradient of 5 to 20 feet per mile. It also slopes toward the streams crossing the lake plain in a narrow area adjoining each stream. The direction of ground-water movement in the Lockport Dolomite in the eastern part of the Niagara Falls area is not known.

## WATER-LEVEL FLUCTUATIONS

Fluctuations of ground-water levels reflect changes in the amount of water stored in an aquifer. A decline in water level shows a decrease in storage in the aquifer, and means simply that discharge from the aquifer is exceeding recharge. A rise in water level indicates the reverse situation--recharge is greater than discharge. In wells tapping unconfined aquifers, water-level fluctuations show changes in the position of the water table. In wells tapping artesian aquifers, water-level fluctuations show changes in artesian pressure.

### Natural fluctuations

Water-level fluctuations of natural origin can be broadly classified as either short- or long-term fluctuations. The short-term fluctuations are produced mainly by changes in atmospheric pressure, ocean tides, and earth tides. Fluctuations due to atmospheric pressure and earth tides occur in the Niagara Falls area but are of relatively little importance in the description of the ground water. Such short-term fluctuations are observed only in wells tapping artesian aquifers. Long-term fluctuations are largely a product of climate, particularly precipitation and temperature. The long-term fluctuations in water levels show changes in the natural rate of recharge to an aquifer compared to its rate of discharge to springs and stream beds.

The most noticeable fluctuation of ground-water levels in the Niagara Falls area are seasonal fluctuations. In general, water levels in the area reach their peak during the spring of the year (March and April) because of the large amount of recharge provided by snow melt and precipitation. Water levels generally decline throughout the summer because most of the precipitation is lost by evaporation and the transpiration of plants. Such water loss is characteristic of the summer growing season. During other seasons substantial amounts of water pass through the soil zone and continue downward to the water table. Water levels generally reach their yearly lows near the end of the growing season during September or October. Thereafter, water levels begin to rise and this rise is more or less continuous through March or April. Because the amount of precipitation is normally evenly spaced throughout the year in the Niagara Falls area (table 4), seasonal fluctuations are more a product of air temperature than of precipitation. The air temperature controls whether precipitation falls as snow or rain, whether the ground is frozen at the time of precipitation, and the length of the growing season; all of these are factors that affect water levels.

The pattern of seasonal fluctuation of ground-water levels described above is observed in wells tapping both bedrock and unconsolidated deposits. Figure 15 shows a yearly hydrograph for well 306-902-1 (a well 36 feet deep

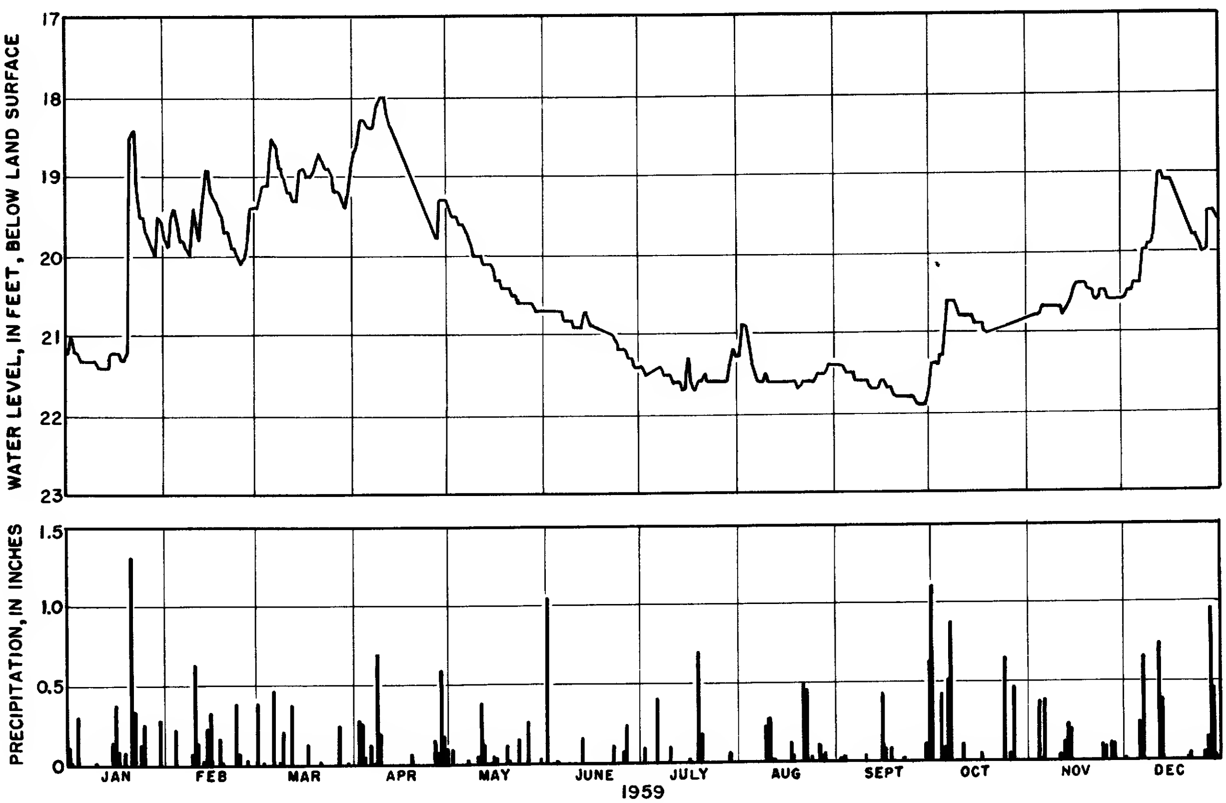


Figure 15.--Hydrograph of well 306-902-1 and daily precipitation at Lewiston, 1959.

in the Lockport Dolomite). As may be seen, the water level varied from a seasonal high of 18 feet below land surface in April to a low of 22 feet below land surface in late September. The greatest rise in water level, and hence the period of greatest ground-water recharge occurred between January and April. The annual fluctuation of 4 feet observed in this well is believed to be typical of wells tapping the upper part of bedrock in the Niagara Falls area. This well is located far enough from the conduits and reservoir of the Niagara Power Project and the area of industrial pumping in Niagara Falls so that the water level is not affected by these manmade activities. Limited data suggest that ground-water levels in the lower part of the Lockport Dolomite also display a seasonal fluctuation. However, the range of this annual fluctuation is not known.

An eight-year record (1950-58) on well 315-859-1, a dug well constructed in silt and clay on the lake plain, shows a pattern of seasonal fluctuation similar to that shown in figure 15. The water level in this well generally varies between 3 and 8 feet below land surface during the year. As in bedrock wells, the highest water level occurs in the spring; the lowest in late summer or early fall. The annual fluctuation of 5 feet is probably typical of wells tapping unconsolidated deposits.

## Effects of reservoir flooding

The pumped-storage reservoir is an important part of the Niagara Power Project (fig. 3). As explained in the introduction, the reservoir is used to store water diverted from the Niagara River that is not needed for power generation during periods of low power demand. The demand for power is greatest during daylight hours but the amount of water that may be diverted from the river is greatest at night. Therefore, the excess water not needed for generating power at night is temporarily stored in the reservoir and is drained during the day. The following paragraphs describe the effects on ground-water levels of both the initial flooding of the reservoir and of daily fluctuations in the altitude of water level inside the reservoir.

The reservoir occupies about 3 square miles of land (1,900 acres) northwest of the city of Niagara Falls (fig. 3). The reservoir is surrounded by an earth- and rock-filled dike containing a clay core which rests directly on the Lockport Dolomite. The entire thickness of dolomite below the dike was grouted to reduce the permeability of the rock and thus impede any outflow of water from the reservoir through the rock.

Partial filling of the reservoir began at 2:15 p.m. on October 26, 1961. Filling continued until the water level inside the reservoir stood at an altitude of 620 feet. (Land surface inside the reservoir ranges from 613 to 625 feet above mean sea level.) Early in December 1961, the water level inside the reservoir was raised to an altitude of 640 feet. Since that time, the reservoir level has fluctuated between 635 and 655 feet. However, during short periods of a few days, the reservoir level has been lowered below 630 feet because of draining to meet power demands. The average operating level of the reservoir is approximately 645 feet.

The effects of reservoir flooding on ground-water levels in the area immediately surrounding the reservoir can be summarized as follows: (1) increases, if any, in water levels in the unconsolidated deposits were slight or were masked by seasonal variations, (2) significant increases in water levels were observed in the upper part of the bedrock, and locally artesian flow commenced, and (3) very slight increases in water levels were observed in the lower part of bedrock.

Table 6 lists changes in ground-water levels following reservoir flooding in a few wells tapping unconsolidated deposits.

The net changes in water level one year following reservoir flooding vary from a rise of 2.9 feet to a decline of 2.6 feet in the wells listed in table 6. It is believed that these wells are reflecting natural fluctuations, and that rises, if any, caused by reservoir flooding are masked by natural fluctuations. A continuous recorder was maintained on well 309-900-8 for a period of one year following flooding of the reservoir. This well responds quickly to precipitation. However, there is no correlation between water-level fluctuations in the well and fluctuations of the reservoir level.

The effect of reservoir flooding on ground-water levels in the upper part of the bedrock (Lockport Dolomite) is shown in figure 16. This map shows the water levels in wells tapping the upper part of bedrock immediately

Table 6.--Changes in water levels in selected wells in unconsolidated deposits following the flooding of the pumped-storage reservoir

| Well number | | Distance from dike (feet) | Depth to bedrock (feet) | Depth to water level (feet below land surface) | | Net change (feet) |
|---|---|---|---|---|---|---|
| Geological Survey | Power Authority | | | Pre-flooding | Post-flooding | |
| 308-859-5 | Ow 118A | 500 | 16.9 | 10.3 (10/26/61) | 8.3 (10/30/62) | +2.0 |
| -9 | 128A | 450 | 11.2 | 8.5 (10/26/61) | 9.8 (10/30/62) | -1.3 |
| 308-900-14 | 179 | 160 | 11.9 | 9.2 (11/14/61) | 6.5 ( 9/13/62) | +2.7 |
| 309-900-6 | 113A | 1,500 | 8.4 | 6.3 (10/26/61) | 3.4 (10/30/62) | +2.9 |
| -8 | 177 | 300 | 9.1 | 5.9 (10/26/61) | 8.5 (11/14/62) | -2.6 |
| 308-901-2 | 115A | 150 | 7.8 | 5.9 (10/26/61) | 3.7 (10/30/62) | +2.2 |

prior to flooding (October 26, 1961) and approximately one year later November 14-15, 1962). During the two days that the post-flooding series of water-level measurements were made, the altitude of the average water level inside the reservoir was 646 feet, which is about the average operating level. The post-flooding measurements were made at about the same time of year as the pre-flooding measurements to nullify the effects of seasonal variation of water levels. Even so, the water level in a reference well (306-902-1), not affected by the reservoir, was about 1.7 feet higher on November 14, 1962, than on October 26, 1962. However, no correction factor was applied to any water level shown in figure 16 to adjust for this seasonal difference. The difference of 1.7 feet is less than the amount some of the wells shown in figure 16 fluctuate in one day in response to the reservoir. Thus, the seasonal difference of 1.7 feet is less than the error caused by making water-level measurements at various times during the same day.

The greatest rise in ground-water levels, as shown by the contours in figure 16, occurred in the interstream areas. The relatively small rises near the streams indicate that the streams are effective drains for the upper part of the bedrock.

The three areas of significant rise in water levels are located between Gill Creek and Fish Creek along the east dike, south of Fish Creek near the northwest corner of the reservoir, and between Gill Creek and the conduits. Within two of these three areas, significant artesian flow developed (fig. 16). The Power Authority drilled 29 relief wells, mainly in the three areas described above, to relieve upward pressures in the rock. Several of these relief wells flow at land surface and are permitted to flow continually. The rate of flow from wells increases and decreases with rise and fall of the

reservoir level. For example, wells 308-900-16 and 309-858-3 (see plate 1 for location) flow at 1 to 7 gpm and 11 to 30 gpm, respectively, depending upon the altitude of water level inside the reservoir.

The rise in water levels in the upper part of bedrock following flooding of the reservoir was caused by movement of water from the reservoir into the Lockport Dolomite and outward along permeable zones in the rock. Movement is through the jointed and fractured zone in the top 10 feet of the rock and through water-bearing zones parallel to bedding which crop out within the reservoir. Observations made during the drilling of relief wells following flooding suggest that most water is moving out via the water-bearing zones parallel to bedding. This is particularly true in wells drilled along the south dike (downdip side) of the reservoir. Most of these wells (drilled after reservoir flooding) obtained little or no water in the top 10 feet of rock. However, below this zone the yield of the wells increased abruptly. Based on the altitude at which increases in yield occurred (personal communication from William Santamour of Uhl, Hall & Rich), it is believed that most of these flowing wells are draining water-bearing zones 5, 6, and 7 in the Lockport Dolomite. (See figure 8.) These 3 zones crop out within the reservoir and apparently are the source of water in the flowing wells on the south side of the reservoir.

The movement of water downward from the reservoir into the Lockport Dolomite is retarded by the cover of impermeable clay and silt (about 10 feet thick) overlying the Lockport. The movement of water outward through the Lockport is retarded by the grout which was placed in the entire thickness of the Lockport beneath the reservoir dike. The loss in head of the water moving through the unconsolidated deposits to water-bearing zones in the Lockport is not known. Also, the effectiveness of the grout curtain cannot be evaluated with certainty because there is no way of knowing how high water levels would have risen if no grouting had been done.

The daily fluctuations of the reservoir level (primarily filling at night and draining during the daytime) produce a daily water level fluctuation in many wells tapping the upper part of the Lockport Dolomite. Figure 17 shows the fluctuation in nine selected wells, which respond in varying degrees to reservoir fluctuations, during a 48-hour period. As shown in the figure, the reservoir level fluctuated about 10 feet during this period. The fluctuation of water levels in the wells varied from a maximum of 14 percent of the reservoir fluctuation in well 308-900-7 to no recognizable fluctuation in three of the wells shown.

The degree to which water levels in wells fluctuate with the reservoir level depends upon the hydraulic connection between the well and the reservoir. The surface distance from the well to the reservoir dike has little effect on the magnitude of the fluctuation. For example, wells 308-900-3 and 308-900-1 are 180 and 540 feet, respectively, from the dike. However, these two wells show water-level fluctuations of approximately equal magnitude (fig. 17).

The wells showing the greatest daily response to reservoir level changes are believed to be wells tapping water-bearing zones which crop out in the reservoir. For example, well 308-900-7 reportedly obtains water from two

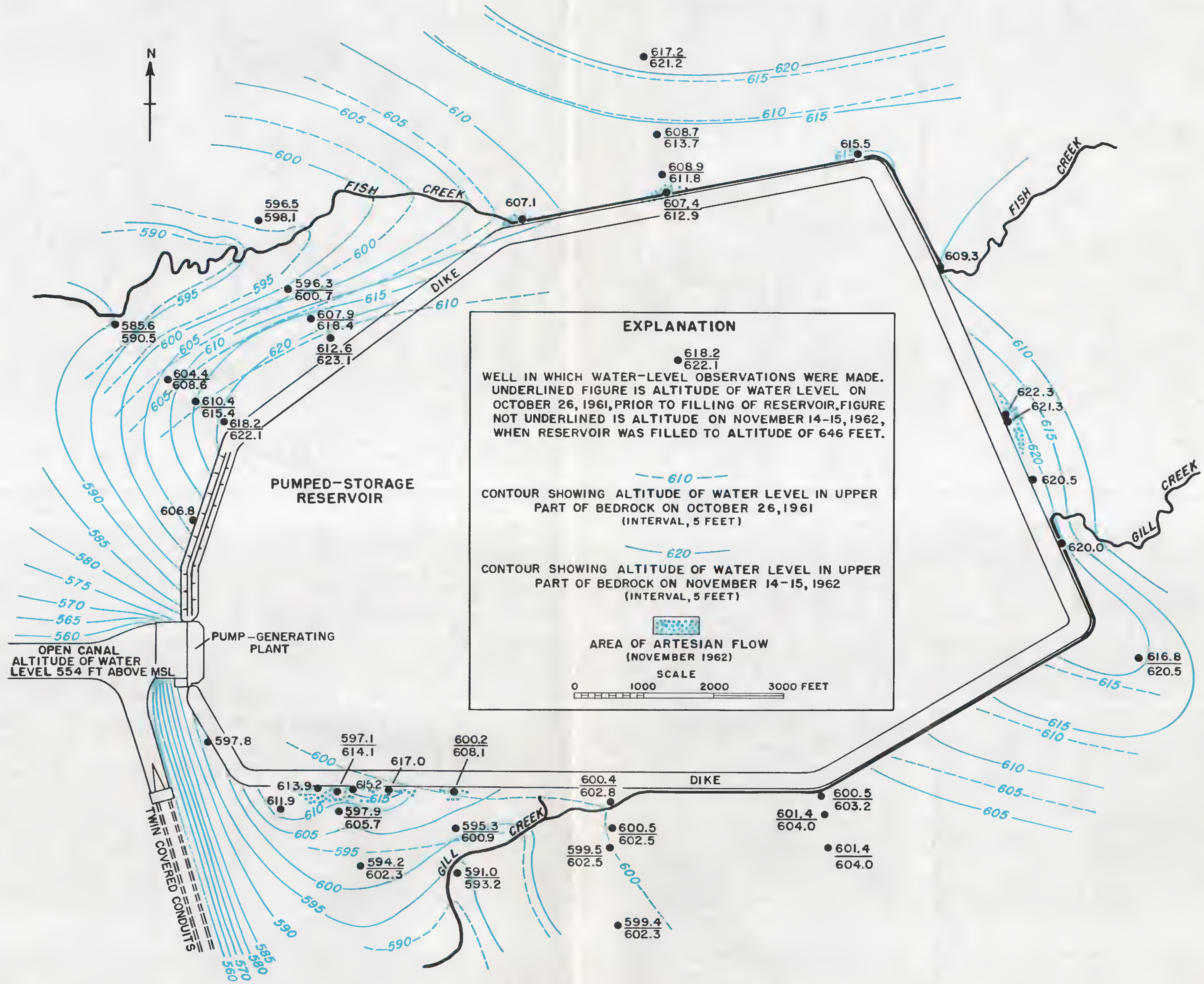


Figure 16.--Map showing the effect of reservoir flooding on water levels in the upper part of the Lockport Dolomite.

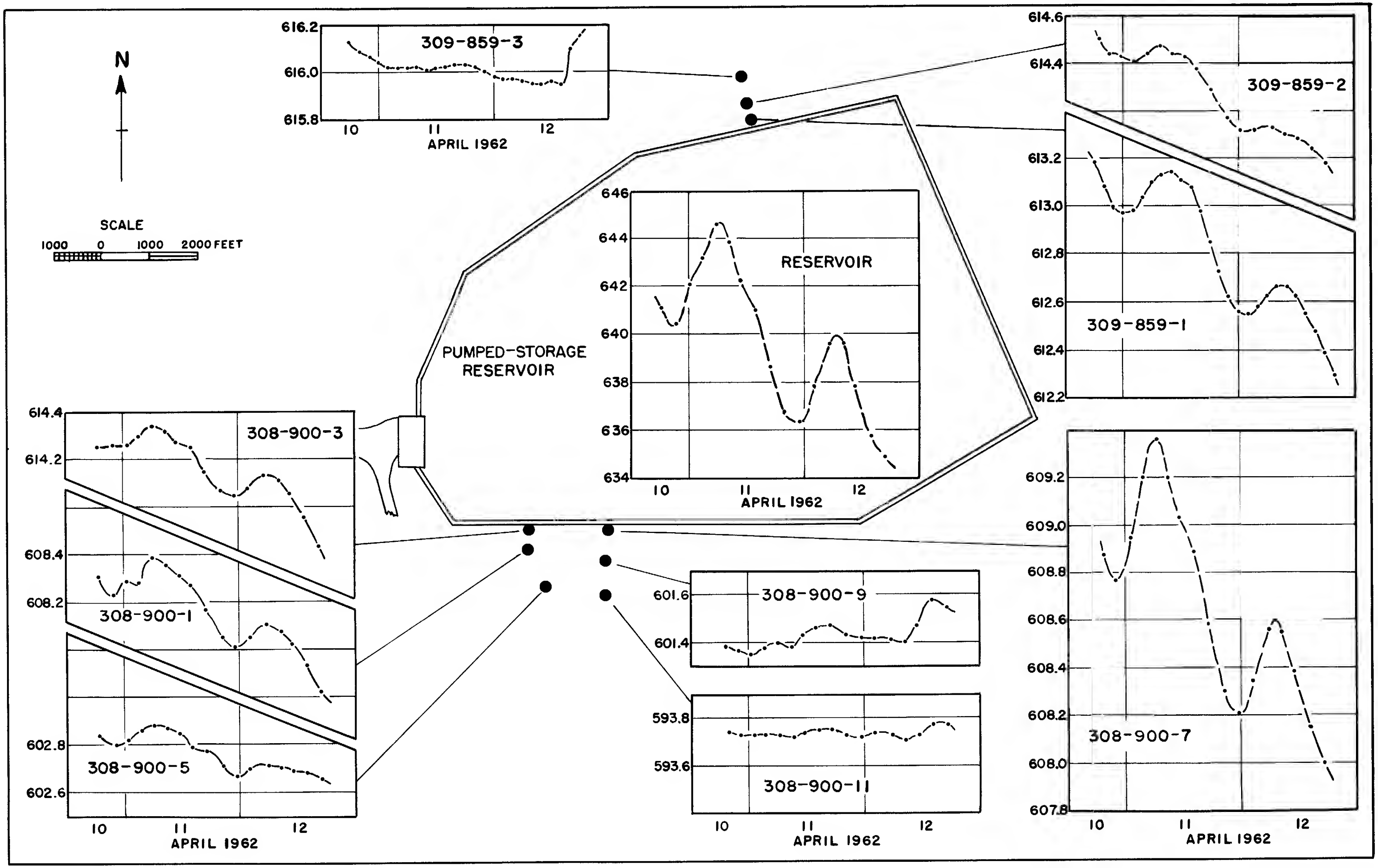


Figure 17.--Fluctuation of ground-water levels in the vicinity of the pumped-storage reservoir during a 48-hour period, April 10-12, 1962.
Water level altitudes are in feet above mean sea level.

distinct levels, one of which is water-bearing zone 6 (fig. 8); however, nearby well 308-900-9 obtains water only from an opening 3 feet below the top of rock (probably a cavity or joint of limited extent). The water level in well 308-900-7 fluctuates very closely with the reservoir level, but well 308-900-9 is little affected by reservoir fluctuations.

It is believed that the water levels (or artesian heads) associated with water-bearing zones 3 through 7 (fig. 8) respond in some recognizable degree to reservoir fluctuations. However, the lowermost water-bearing zones in the Lockport (zones 1 and 2), which crop out north of the reservoir, are not affected by the reservoir. This lack of effect on the two lowest zones is shown by wells 309-859-1, -2, and -3 (fig. 17). Well 309-859-1 taps zones 1, 2, and 3, well 309-859-2 taps zones 1 and 2 and is probably connected to zone 3 via fractures at the top of rock, and well 309-859-3 taps only zones 1 and 2. As can be seen in figure 17 wells 309-859-1 and -2 fluctuate closely with the reservoir, but well 309-859-3 which taps only zones 1 and 2 is not affected by daily reservoir fluctuations.

# . . . DEVELOPMENT OF GROUND WATER

The development of ground water in the Niagara Falls area has been and will continue to be directed principally toward obtaining small domestic and farm supplies in the rural sections. A few moderate to large supplies have been obtained from the only important aquifer, the Lockport Dolomite. The development of ground-water supplies has been limited by two factors: (1) the lack of sand and gravel deposits, which provide most of the large ground-water supplies elsewhere in New York, and (2) the abundant supply of water available from the Niagara River.

## METHODS OF RECOVERY

### WELLS

Wells in the Niagara Falls area are classified according to method of construction as either dug or drilled. In general, dug wells are constructed to obtain water from unconsolidated deposits, and drilled wells are constructed to obtain water from bedrock. Wells constructed by other methods, such as driving, augering, and jetting, are rare in the Niagara Falls area.

#### Drilled wells

Drilled wells are more numerous in the Niagara Falls area than dug wells. Most drilled wells are constructed by the cable-tool method, although a few have been constructed by rotary methods. Wells drilled into the bedrock are always constructed as open holes below the top of rock; that is, the well is cased only through the unconsolidated deposits to the top of rock. The firmness with which the casing is seated into bedrock varies with the formation tapped. In the Lockport Dolomite it is common practice to seat the casing firmly into the rock. The well then obtains water only from openings in the rock. Wells drawing from the Lockport nearly always provide an adequate supply of water for domestic, farm, and small commercial uses. In contrast it is common practice for drillers to jack the casing in a well back and forth in the upper few inches of Queenston Shale in an attempt to obtain water from the fractured zone at the top of rock. Thus, wells drilled into the Queenston Shale commonly have casings seated loosely at or slightly above the top of rock. This loose seating permits water to enter the well from the fractured zone at the top of the shale and also from the overlying unconsolidated deposits. Wells constructed with the casing loosely seated will usually provide an adequate domestic water supply.

A few drilled wells which tap only unconsolidated deposits are found in the Niagara Falls area. Such wells are usually constructed with open-end casings. In order to provide small supplies of water, these wells must penetrate sand or gravel. The insertion of well screens or slotted casings, generally not used in the Niagara Falls area, would greatly increase the yield of such wells.

Drilled wells to be used for domestic or farm supplies are generally 6 to 8 inches in diameter. Wells constructed to provide moderate to large industrial supplies are generally 10 to 24 inches in diameter. The depth of drilled wells varies according to the desired yield of the well. Most wells drilled in the Lockport Dolomite for domestic and farm supplies are less than 40 feet deep. Wells in the Queenston are generally deeper. Although drilled wells in the Queenston obtain most of their water from the top of rock, which is commonly 30 to 50 feet below land surface, these wells are drilled deeper into the rock to provide storage. Wells in the Lockport which provide moderate to large water supplies for industrial and commercial uses usually penetrate the entire thickness of the formation, and thus are commonly 100 to 150 feet deep.

The development of wells (the use of various methods to increase the yield of a well) is generally limited to bailing or pumping in the Niagara Falls area. Other methods of development such as acidizing and dynamiting are seldom practiced. Bailing, however, is quite effective in developing wells drilled by the cable-tool method. The surging effect of bailing removes rock flour which may clog water-bearing openings in bedrock wells, and removes clay and silt from wells which tap sand and gravel.

### Dug wells

Dug wells, with few exceptions, are constructed to obtain water from unconsolidated deposits. Most dug wells in the area are found in the lake plain north of the Niagara escarpment because the unconsolidated deposits are thickest there. Dug wells are uncommon south of the escarpment because of the thinness of the unconsolidated deposits, and because drilled wells into the Lockport Dolomite provide a much more dependable source of water.

The dug wells in the Niagara Falls area are generally 2 to 3 feet in diameter and 15 to 20 feet deep. The older wells were dug by hand and then lined with field stone. Dug wells are generally constructed now by digging a hole with a power shovel. A few feet of crushed rock may be placed in the bottom of the hole before porous concrete pipe or tile is inserted.

Dug wells are effective means of obtaining water from deposits of very low permeability such as glacial till and lake clay and silt. As mentioned previously most water in such deposits is found in a "washed zone" near the top of rock or in sand lenses widely scattered throughout the deposits. Wells constructed with open-stone curbing or perforated tile allow water from thin sand lenses to drain readily into the well. A large-diameter-dug well which taps the "washed zone" at the top of rock will obtain more water from this zone than a small-diameter-drilled well. Dug wells, because of their large volume, have the additional advantage of providing a large reservoir for storage between periods when the well is not pumped.

## SPRINGS

Springs are not widely utilized as ground-water supplies in the Niagara Falls area. Springs are common along the Niagara escarpment but rarely occur elsewhere in the area. (See plates 1 and 3.)

Most of the springs along the escarpment originate near the base of the Lockport Dolomite. The source is nearly always seepage from bedding joints at the contact between the DeCew Limestone Member of Williams (1919) and the Gasport Limestone Member of the Lockport (water-bearing zone 2 in fig. 8). The springs occur where vertical joints intersect the water-bearing zone. Enlargement of both vertical and bedding joints is common at the springs, and in some cases has proceeded to the point where small caves have developed.

Springs are uncommon along the cliffs of the Niagara River Gorge. This lack of springs probably results from the development of extensive open vertical joints parallel to the face of the gorge. These joints drain water readily from the Lockport Dolomite through the underlying rocks and talus to the river. (See figure 6.)

Notable exceptions to the lack of springs along the gorge are springs 309-902-2Sp and -3Sp which are located just south of the Niagara escarpment (pl. 1). These springs are located in caves developed by solution of the shaly dolomite of the DeCew Member of Williams (1919) of the Lockport. The source of the springs, like the source of most springs along the escarpment, are bedding joints at the contact between the DeCew and Gasport Members (water-bearing zone 2 in fig. 8). Extensive solution features, such as sink holes, exist in the area drained by these two springs. Fish Creek, which crosses the area, loses water as it flows across the bedrock, and apparently contributes a major part of the water discharging from the springs. Dye introduced into Fish Creek reappeared at the springs, 1,000 feet away, 38 minutes after introduction (personal communication from C. P. Benziger of Uhl, Hall & Rich). The yield of these springs is therefore highly variable; the yields varying from about 15 gpm during dry periods to reportedly thousands of gallons per minute following heavy rains or periods of melting snow. The water from springs 309-902-2Sp and -3Sp is polluted by nearby septic tanks as shown by the strong odor of sewage and the sudsy character of the water.

The yield of single springs in the Niagara Falls area ranges from about 2 to 30 gpm during the dry parts of the year. The yields of most springs increase following rains but not nearly so much as the increase noted for springs 309-902-2Sp and -3Sp in the discussion above. Spring 310-859-6Sp is the only spring in the area utilized as a water supply on a year-round basis. This spring provides an adequate domestic supply for a trailer court with eight families.

# PRESENT UTILIZATION

An estimated 10 mgd (million gallons per day) of ground water was obtained from wells in the Niagara Falls area during 1961-62. This figure contrasts with an estimated 60 mgd of water obtained from surface sources

during the same period. Approximately 216,000 persons (U.S. Census of 1960) live in the Niagara Falls area (which includes about three-quarters of Niagara County and one-quarter of Orleans County). Of this number, about 36,000 persons obtain their domestic water supply from wells. The remaining 180,000 persons obtain water from one of the three public supply systems: the City of Niagara Falls System, the City of Lockport System, or the Niagara County Water District. These three systems obtain their water from the Niagara River.

The principal uses of ground water in the Niagara Falls area during 1961-62 were:

| Use | Average pumpage |
|---|---|
| Agricultural | 0.5 mgd |
| Air conditioning | .1 |
| Domestic | 1.3 |
| Industrial | 8.0 |
| Total | 9.9 mgd |

An additional 0.7 mgd was pumped from wells by three small public systems prior to 1961. However, these systems discontinued use of ground water during 1961 when water was obtained from the Niagara County Water District.

Approximately 90 percent of the ground water used in the Niagara Falls area (9 mgd) is obtained from the Lockport Dolomite. The remaining 1 mgd used in the area is obtained mostly from unconsolidated deposits and the Queenston Shale.

## DOMESTIC AND FARM SUPPLIES

Ground water provides the domestic water supply of approximately 36,000 persons living in the Niagara Falls area, as noted above. In addition, most of the water used for agricultural purposes in the area is obtained from wells. The requirements for domestic supplies are small, about 35 gpd (gallons per day) per person. Thus, a well yielding a few hundred gallons per day provides an adequate domestic supply. Farm supplies generally require somewhat more water; a few hundred to a few thousand gallons per day. The actual amount depends on the number and kind of animals on the farm.

The ease of developing the small supplies required for domestic and farm uses varies throughout the area because of the local geology, as noted previously. In the area south of the Niagara escarpment, adequate water supplies for domestic and agricultural uses are readily obtained from small-diameter-drilled wells in the Lockport Dolomite. On the Lake Plain north of the escarpment, the development of adequate supplies is more problematical. Some drilled wells in the Queenston Shale, and some dug wells in the lake deposits (clay, silt, and fine sand) will not supply the relatively small amounts of water required for domestic and farm supplies.

The chemical quality of ground water from bedrock wells is generally poor. This water is very hard and often contains more than 1,000 ppm of dissolved minerals, a much higher concentration than contained in water

ordinarily available from most municipal water systems. Salty water is found in a few wells in the Queenston Shale, particularly in the area immediately north of the Niagara escarpment. Hydrogen sulfide, which gives an objectionable taste and odor to water, is found in about one-third of the wells in the Lockport. Because of the poor chemical quality, treatment of the ground water is often practiced. Zeolite softening to reduce hardness and chlorination to remove hydrogen sulfide are the two most commonly used treatment methods.

## INDUSTRIAL AND PUBLIC SUPPLIES

By far the greatest use of ground water in the Niagara Falls area is by industries. Approximately 8 mgd of ground water (80 percent of that used in the area) is used for industrial purposes, mainly for cooling and processing by chemical industries in the city of Niagara Falls. This water is obtained from a few wells of exceptionally high yield in the Lockport Dolomite. (See wells 304-901-2, -5, -6, and -7 in table 7.) These wells are located within 1,500 feet of the Niagara River and are believed to obtain most of their water by induced infiltration from the river, as discussed in the earlier section on occurrence of water in the Lockport.

Water from the high-yield industrial wells is characterized by much better chemical quality than water obtained elsewhere from the Lockport Dolomite. An analysis of water from one of the industrial wells, well 304-901-6, is shown graphically in figure 11; it indicates water from the well is slightly more mineralized than Niagara River water. An important advantage of water pumped from the industrial wells in comparison with water pumped directly from the river, is the relatively narrow range in temperature of the well water which makes it particularly desirable for use in cooling and processing by the chemical industry.

A few industries have obtained small to moderate supplies (150 gpm or less) from wells in the Lockport in other parts of the area. In general, most wells in the Lockport outside the area of infiltration supplies adjacent to the Niagara River (pl. 2), provide either inadequate industrial supplies or water of poor quality. A number of wells have been abandoned by industries in the Niagara Falls area for these reasons. (See wells 304-900-4, -5, and -6, 305-900-3, 308-901-6, and 308-902-7 in table 7.)

Three small public supply systems used ground water prior to 1961. The average daily pumping rate and water-bearing unit of wells used in these systems are as follows:

| System | Average daily pumping rate | Water-bearing unit |
|---|---|---|
| Gasport in town of Royalton | 36,000 gpd | Pleistocene sand |
| Village of Medina | 600,000 gpd | Lockport Dolomite |
| Village of Middleport | 100,000 gpd | Lockport Dolomite |

These three communities discontinued the use of ground water in 1961, and since then have purchased water from the Niagara County Water District. The largest of the three systems, Medina, formerly obtained water from two dug wells, over 20 feet in diameter, and a small-diameter-drilled well in the Lockport Dolomite. Combined pumpage from these three wells varied from 400,000 to 900,000 gpd. The yield of the wells varied seasonably because of the seasonal fluctuation in the position of the water table. The yields were lowest during August and September when the need for water by the food-processing plants in Medina was greatest.

Small to moderate supplies of ground water (5 to 150 gpd) are utilized by a number of trailer courts and a few small military installations in the Niagara Falls area. Nearly all of these supplies are obtained from the Lockport Dolomite. However, the poor chemical quality of the water is a problem locally. For example, water obtained from wells 308-850-1 and -2, which is used by a small Air Force station, is too highly mineralized to be used without treatment. (See chemical analyses for these wells in table 9.) Zeolite softening and chlorination improve the chemical quality of the water.

## POTENTIAL DEVELOPMENT

Ground water should continue to supply two important needs for a long time in the foreseeable future. These are: (1) small supplies for domestic and farm use in the sparsely populated sections of the region, and (2) large supplies of ground water for industrial use within a small area along the Niagara River. All other water needs are probably most economically met by the abundant supplies available from the Niagara River and Lake Ontario.

The prospects for future development of large ground-water supplies in the Niagara Falls area are limited. The only part of the area offering such prospects is the small area adjacent to the Niagara River where wells obtain large supplies (up to 2,200 gpm) by induced infiltration from the river (pl. 2). Within this area additional large supplies can probably be obtained from the Lockport Dolomite. However, the perennial yield of the aquifer in this area is not known. Based on present knowledge (particularly data from a pumping test on well 304-901-2), it is believed that a few additional wells yielding more than 1,000 gpm can be constructed. However, consideration would have to be given to the proper spacing of additional wells to minimize interference between new wells and the existing wells.

The development of small to moderate supplies (5 to 150 gpm), adequate for domestic, agricultural, and commercial uses is feasible throughout the area underlain by the Lockport Dolomite. (See plates 2 and 3.) The yields of individual wells vary, although wells which may be pumped at 20 to 30 gpm for short periods can be constructed throughout nearly all of this area. This situation will exist as long as the region is predominantly rural. However, if extensive urbanization occurs, resulting in many closely spaced wells, yields of individual wells will decline. On the other hand, a small degree of urbanization will probably not materially affect the yield of wells. In small hamlets of a few hundred persons, the yield of wells tapping the Lockport in adjacent houses is not noticeably less than the yield of

wells in rural areas. The generally poor chemical quality of water in the Lockport presents more of a problem than the availability of an adequate quantity of water. Treatment of the water, particularly to reduce hardness or remove hydrogen sulfide, is desirable but of some expense and inconvenience.

The development of even the very small supplies needed for domestic and farm use will continue to be difficult in the part of the area underlain by the Queenston Shale (pl. 3). The impermeable nature of the shale and the overlying clay and silt makes the prospects for the development of any but very small supplies improbable in this area. A few small deposits of sand and gravel occur in the area, but are too limited in areal extent to alter the overall appraisal that future development of ground-water supplies will be very limited.

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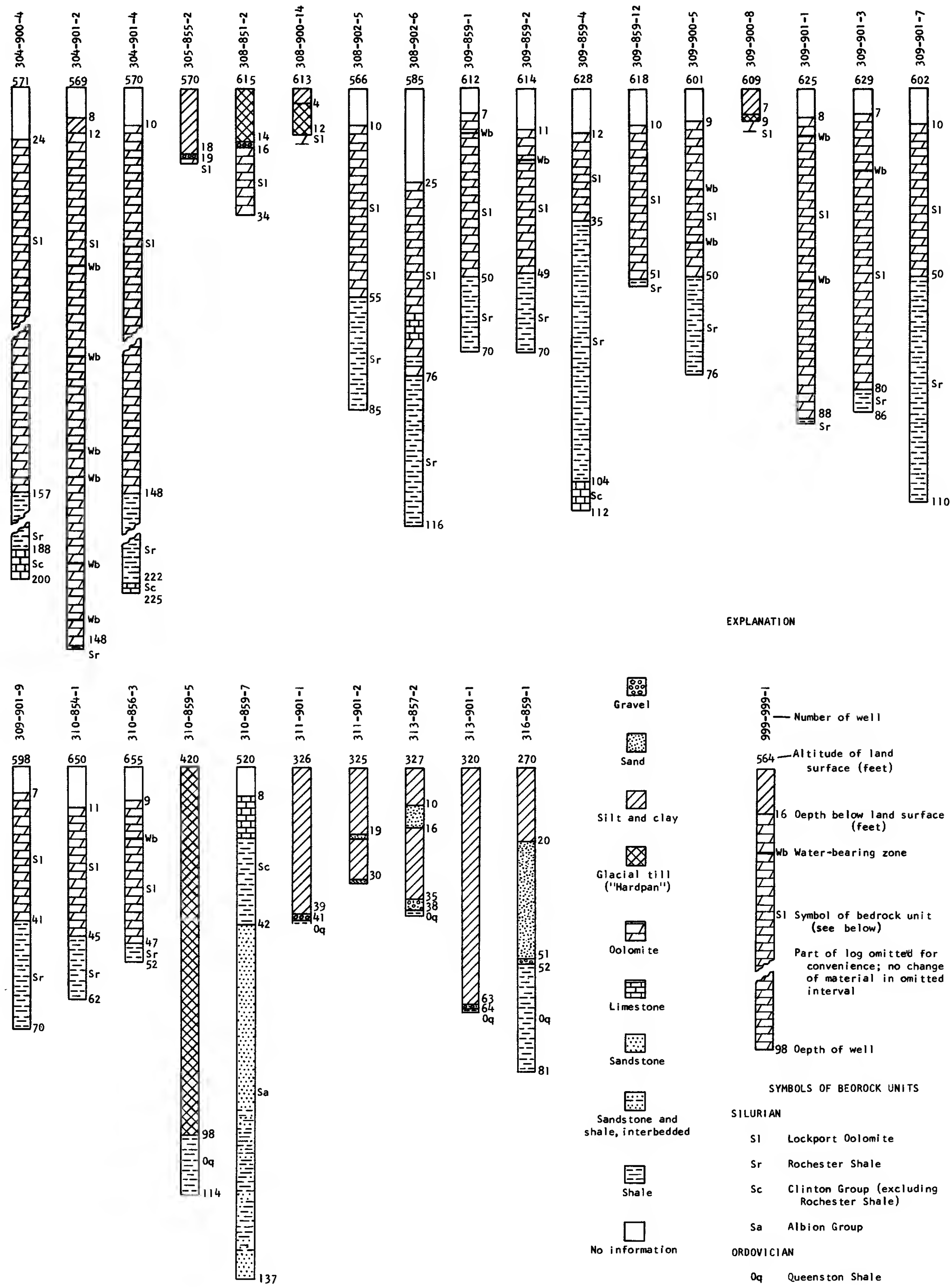
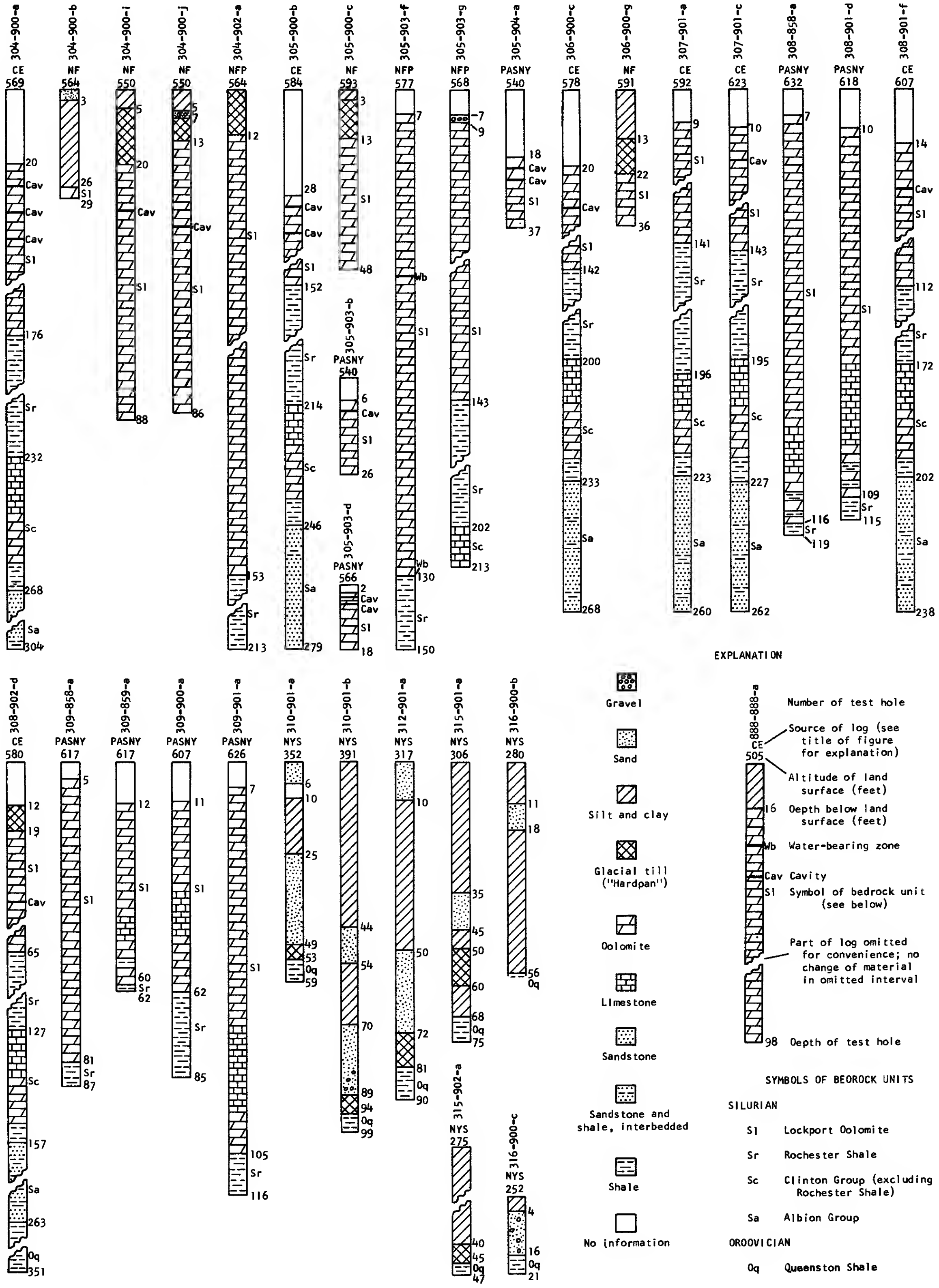



Location of wells is shown in plates 1 and 2.

**Figure 18.--Graphical logs of wells.**




Location of test holes is shown in plates 1 and 3. The source of information is indicated by the following abbreviations: CE, U. S. Army Corps of Engineers; NF, City of Niagara Falls; NFP, Niagara Falls Power Co.; NYS, N. Y. State Bureau of Soil Mechanics; PASNY, Power Authority of the State of New York.

**Figure 19.--Graphical logs of test holes.**

## Table 7. --Records of selected wells in the Niagara Falls area

Well number: See "Well-Numbering System" in text for explanation.

Owner: PASNY - Power Authority of the State of New York.

Type of well: Aug - augered
Drl - drilled
Dug,Drl - dug and drilled

Depth of well: All depths below land surface.
a - about
r - reported
all others measured

Depth of casing: All depths below land surface.
drilled wells - depth to bottom of casing or depth to top of slots or screen
dug wells - depth omitted for stone-curbed wells
- depth to bottom of tile or culvert pipe
a - about
r - reported

Diameter of wells: Diameters of dug wells are approximate.
Where two or more sizes of casing were used the top and bottom diameters are given.

Depth to bedrock: All depths below land surface.
a - about
r - reported
all others measured

Water-bearing material: Oq - Queenston Shale
Qd - Pleistocene deposits, undifferentiated
Qlc - Pleistocene lake deposits; silt and clay
Qls - Pleistocene lake deposits; sand
Qsg - Pleistocene sand and gravel
Qti - Pleistocene glacial till
Sa - Albion Group
Sc - Clinton Group
Sl - Lockport Dolomite

Altitude above sea level: s - altitude of land surface measured by surveying instruments and given to nearest foot.
All others estimated from topographic maps to nearest 5 feet.

Measuring point, position: Given in feet above land surface, except those preceded by a minus (-) sign which are below land surface.
LS - at land surface

Water level below land surface: All water levels are below land surface except those preceded by a plus (+) sign which are above land surface.
r - reported
all others measured by personnel of the U.S.G.S. or Uhl, Hall & Rich.
c - water level while PASNY conduits were dewatered
d - water level after PASNY conduits were flooded
F - series of water-level measurements on file in U.S.G.S. office, Albany, N. Y.
g - water level prior to flooding of PASNY reservoir
h - water level after PASNY reservoir flooded to elevation of about 640 feet above mean sea level
p - pumping effects probable

Yield: Yield in gallons per minute based on pumping test or continuous pumpage except: b - yield based on short bailing test
e - estimated yield
r - reported yield by owner
> greater than
< less than

Use: A - abandoned
C - commercial
D - domestic
De - destroyed
Dr - drainage
Dw - dewatering
I - industrial
In - institutional
Ir - irrigation
O - observation
PR - pressure-relief well
PS - public supply
S - stock
T - test
U - unused

Remarks: Well number - PASNY - well number assigned by Power Authority of the State of New York.
OW - observation well
PR - pressure-relief well
R - residential well used for observation
WP - well finished with screened well point
anal. - chemical analysis in this report
Cl - chloride content in parts per million
dd - drawdown
gpm - gallons per minute
$H_2S$ - noticeable odor of hydrogen sulfide
inadequate - reported inadequate by owner
log - graphical log in this report
LS - land surface
pt - pumping test data on file, U.S.G.S. office, Albany, N. Y.
rT - temperature, in degrees Fahrenheit, reported by owner
salty - salty to taste
T - temperature, in degrees Fahrenheit, measured by U.S.G.S.

Table 7.--Records of selected wells in the Niagara Falls area (Continued)

| Well number | Owner | Year completed | Type of well | Depth of well (feet) | Depth of casing (feet) | Diameter (inches) | Depth to bedrock (feet) | Water-bearing material | Altitude above sea level (feet) | Measuring point: Description | Measuring point: Position | Water level: Below land surface (feet) | Water level: Date | Yield (gallons per minute) | Use | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 304-851-1 | D. Freck | 1955 | Drl | 68 | -- | 6 | r60 | Sl | 575 | Top of casing | 0.9 | 18.8 | 10/20/60 | b8 | D | Anal.; $H_2S$; salty; may obtain some water from overlying Salina Group. |
| 304-857-1 | Wendt Dairy | 1935 | Drl | r35 | r22 | 8 | r20 | Sl | 570 | -- | -- | -- | -- | r100 | C, U | $H_2S$. |
| 304-900-1 | PASNY | 1958 | Drl | r120 | -- | 12 | a10 | Sl | 570 | -- | -- | -- | -- | >100 | Dw | |
| -4 | Hooker Chemical Co. | 1935 | Drl | r204 | r25 | r6 | r25 | Sl | s571 | -- | LS | r22 | 2/26/36 | r>350 | I, A | Log; pumped at 150 gpm with 19 ft dd; rT 57; $H_2S$; abandoned because of poor chemical quality. |
| -5 | do. | 1907 | Drl | r296 | -- | r8 | 18 | Sl | s571 | -- | LS | r18 | -- | r>50 | I, A | Pumped at 50 gpm with 27 ft dd; rT 51; $H_2S$; abandoned because of poor chemical quality and inadequate yield. |
| -6 | do. | 1910? | Drl | r300 | -- | r8 | r18 | Sl | s571 | -- | LS | r18 | -- | -- | I, A | Abandoned because of poor chemical quality and inadequate yield. |
| 304-901-1 | E. I. du Pont de Nemours & Co. | 1934 | Drl | r185 | -- | r6 | r12 | Sl | s569 | -- | LS | r17 | -- | r750 | T | |
| -2 | do. | 1934 | Drl | r148 | r14 | 24, 18 | r12 | Sl | s569 | -- | LS | r17 | 2/27/37 | 2,200 | I | Log; anal.; pumped at 1,750 gpm with 78 ft dd; pumped continuously at 1,700-1,800 gpm; rT 50-53 yearly variation. |
| -3 | do. | -- | Drl | r110 | -- | r6 | -- | Sl | 570 | -- | -- | -- | -- | r400 | T | |
| -4 | do. | 1932 | Drl | r225 | -- | r8 | r10 | Sl | 570 | -- | -- | -- | -- | r70 | T | Log; pumped at 70 gpm with 150 ft dd. |
| -5 | Olin Mathieson Chemical Corp. | 1936 | Drl | r125 | r25 | 24, 18 | r10 | Sl | s570 | Center of pressure gage | 1.0 | p34 | 12/ 4/61 | r3,450 | I, U | Pumped at 3,450 gpm with 16 ft dd originally; present yield 1,700-1,800 gpm; yield affected by nearby pumping; rT 50-54. |
| -6 | do. | 1947 | Drl | r125 | r25 | 20, 19 | r10 | Sl | s570 | -- | -- | -- | -- | 2,100 | I | Anal; pumped at 1,900 gpm continuously in 1961; yield affected by nearby pumping; rT 50-54. |
| -7 | do. | 1947 | Drl | r125 | r25 | 20, 19 | r10 | Sl | 570 | Center of pressure gage | LS | p78 | 12/ 4/61 | 2,100 | I | Original static level reported 34 ft below LS; pumped at 2,100 gpm with 21 ft dd; rT 50-54. |
| -8 | do. | 1936 | Drl | r125 | -- | r6 | r10 | Sl | 570 | -- | -- | -- | -- | 500 | T | |
| 305-853-1 | F. Lemke | -- | Dug, Drl | r50 | -- | 36, 6 | r25 | Qd, Sl | 575 | Top of brick curbing | LS | 11.9 | 10/20/60 | -- | S | Cl 60 10/20/60; $H_2S$. |
| -2 | R. Licht | -- | Dug, Drl | -- | -- | 36, r6 | -- | Sl | 580 | Top of well cover | .3 | 8.8 | 10/26/60 | -- | D | Cl 42 10/26/60; $H_2S$. |
| 305-855-1 | N. Moll | 1952 | Drl | 25 | -- | 6 | -- | Sl | 570 | Top of casing | .6 | 7.4 | 10/20/60 | -- | O, U | $H_2S$. |
| -2 | do. | 1955 | Drl | 20 | r18 | 6 | r19 | Qsg, Sl | 570 | do. | 1.5 | 11.1 | 10/20/60 | b15 | D, U | Log; aquifer is gravel at top of rock. |
| 305-900-1 | PASNY | 1958 | Drl | 139 | a20 | 12 | a20 | Sl | s570 | do. | 1.0 | F,c106.3<br>d18.4 | 12/20/60<br>1/ 5/61 | 950 | Dw, O | Anal.; pt; water level controlled by PASNY conduits; pumped at 950 gpm with 82 ft dd; $H_2S$. |
| -2 | do. | 1960 | Drl | 100 | -- | 6 | -- | Sl | s583 | do. | 4.2 | F,c95.3<br>d30.6 | 12/19/60<br>1/13/60 | -- | O | PASNY OW 149; water level controlled by PASNY conduits. |
| -3 | Union Carbide Chemical Co. | 1940 | Drl | r100 | r6 | r6 | r4 | Sl | s577 | Floor level | 2.0 | r28 | 1940 | >100 | I, A | Anal.; pumped at 86 gpm with 4 ft dd; rT 52; $H_2S$; salty; abandoned because of poor chemical quality. |
| 305-902-1 | A. Spallino | 1959 | Drl | r110 | -- | 8 | a3 | Sl | 595 | -- | -- | -- | -- | r>100 | C | |
| -2 | do. | 1961 | Drl | 113 | 3 | 6 | 3 | Sl | 595 | Top of rock surface | -3.0 | 82.8 | 9/12/61 | b20 | Dr | |
| 305-903-1 | Cataract Theatre Corp. | 1936 | Drl | r112 | r19 | 8 | r12 | Sl | 570 | Center of pressure gage | -7.5 | 33 | 9/12/61 | >250 | C | Pumped at 250 gpm with 31 ft dd; T 62 9/12/61. |
| -2 | S. S. Kresge Co. | 1938 | Drl | r140 | -- | 8 | a4 | Sl | 570 | -- | -- | -- | -- | r90 | C | rT 56 11/43; inadequate in summer. |
| 306-853-1 | E. Lass | 1952 | Drl | 49 | r40 | 6 | r40 | Sl | 580 | Top of casing | 1.0 | 6.3 | 10/26/60 | -- | D | Cl 45 10/26/60. |

Table 7.--Records of selected wells in the Niagara Falls area (Continued)

| Well number | Owner | Year completed | Type of well | Depth of well (feet) | Depth of casing (feet) | Diameter (inches) | Depth to bedrock (feet) | Water-bearing material | Altitude above sea level (feet) | Measuring point: Description | Measuring point: Position | Water level: Below land surface (feet) | Water level: Date | Yield (gallons per minute) | Use | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 306-854-1 | R. Jaeger | -- | Drl | r19 | -- | 6 | r19 | Qsg | 580 | -- | -- | -- | -- | b20 | D | Cl 18 10/26/60; $H_2S$; aquifer is gravel at top of rock. |
| 306-859-1 | C. Swearengen | -- | Drl | 28 | -- | 6 | -- | Sl | s608 | Top of casing | LS | F,12.1 | 8/ 8/60 | -- | D, U | PASNY 299. |
| -2 | W. Mick | 1950 | Drl | 49 | -- | 6 | -- | Sl | s624 | do. | 0.8 | F,34.6 | 8/ 8/60 | -- | D, U | PASNY 276. |
| -3 | L. Toni | 1952 | Drl | 31 | -- | 6 | -- | Sl | s605 | do. | .7 | F,c16.6<br>d13.9 | 8/ 8/60<br>6/ 2/61 | -- | D | PASNY PR 43. |
| -4 | Haggerty | -- | Drl | 40 | -- | 6 | -- | Sl | 605 | do. | .9 | F,28.4 | 10/ 5/60 | -- | D, U | PASNY PR 18. |
| 306-902-1 | City of Niagara Falls | 1958 | Drl | 36 | 17 | 8 | 16 | Sl | s596 | do. | 3.1 | F,c22.0<br>d21.7 | 10/19/60<br>10/19/61 | b21 | O | |
| -2 | American Sales Book Co. | 1940 | Drl | r119 | r15 | 8 | r15 | Sl | 590 | -- | LS | r16 | -- | 100 | i | Pumped at 100 gpm with 64 ft dd; $H_2S$. |
| 306-903-2 | Bellview Theatre Corp. | 1939 | Drl | r120 | -- | 8 | r15 | Sl | 595 | -- | -- | -- | -- | r50 | C, U | inadequate; T 59 9/16/61; $H_2S$. |
| 307-859-1 | -- | 1959 | Drl | 75 | 12 | 6 | 12 | Sl | s613 | Top of casing | 3.0 | F,g13.2<br>h10.3 | 10/26/61<br>11/15/62 | b14 | O | PASNY OW 119; packer 39.1 ft below LS; water level below packer g41.8 10/26/61 and h35.5 11/15/62. |
| -3 | W. Lozan | 1958 | Drl | 31 | r15 | 6 | r15 | Sl | 620 | do. | 1.2 | F,12.5 | 8/ 8/60 | b >30 | D, U | PASNY 342. |
| -4 | J. Patterson | -- | Drl | 34 | -- | 6 | -- | Sl | s609 | Top of flange | .9 | F,34.0 | 8/ 7/60 | -- | D, U | PASNY 259. |
| 307-900-1 | H. Moore | 1958 | Drl | 49 | 24 | 6 | 24 | Sl | s597 | Top of casing | 4.0 | F,c24.2<br>d24.3 | 10/ 1/60<br>10/ 4/61 | b9 | O | PASNY OW 102. |
| -2 | -- | 1958 | Drl | 73 | 15 | 6 | 15 | Sl | s590 | do. | 3.8 | F,c23.5<br>d22.0 | 9/29/60<br>10/ 4/61 | -- | O | PASNY OW 105; water level is affected by Gill Creek. |
| -3 | Falls Auto-View Drive-in Theatre | 1958 | Drl | 74 | 19 | 6 | 19 | Sl | s595 | do. | 3.2 | F,c26.3<br>d23.8 | 9/29/60<br>10/ 4/61 | b45 | O | PASNY OW 101; water level is affected by Gill Creek. |
| -4 | PASNY | 1958 | Drl | 110 | 17 | 6 | 13 | Sl | s607 | do. | 4.1 | F,c91.0<br>d46.2 | 10/ 3/60<br>10/ 3/61 | b43 | O | PASNY OW 100; T 51 7/23/58; $H_2S$. |
| -5 | W. Belden | -- | Drl | 32 | -- | 6 | -- | Sl | s604 | do. | .7 | F,c20.6<br>d19.4 | 8/ 8/60<br>6/ 1/61 | -- | D | PASNY 249. |
| -6 | A. W. Nuzum | 1955 | Drl | 55 | r10 | 6 | r10 | Sl | s602 | do. | .5 | F,c16.1<br>d12.3 | 8/ 8/60<br>6/ 2/61 | b > 10 | C | PASNY 3; slightly salty. |
| -7 | E. Schul | 1957 | Drl | 25 | -- | 6 | -- | Sl | 600 | do. | 2.2 | F,15.8 | 8/ 8/60 | -- | D, U | PASNY 343; inadequate. |
| -8 | Military Road School | -- | Drl | 45 | -- | 6 | -- | Sl | s611 | Top of plug in 4-inch pipe | 2.0 | F,c21.4<br>d14.8 | 8/ 8/60<br>6/ 2/61 | -- | i | PASNY 124. |
| -9 | L. Cora | 1940 | Drl | 26 | -- | 6 | -- | Sl | s601 | Top of casing | .5 | F,c20.0<br>d17.4 | 8/ 8/60<br>6/ 2/61 | -- | D, U | PASNY 121; $H_2S$. |
| 307-901-1 | B. Banfield | -- | Drl | 29 | -- | 6 | -- | Sl | s621 | do. | .7 | F,c17.5<br>d12.3 | 8/ 8/60<br>6/ 1/61 | -- | D | PASNY 102; anal. |
| -2 | C. La Gukle | 1950 | Drl | 29 | -- | 6 | -- | Sl | s620 | Top of coupling | 1.1 | F,c17.7<br>d12.8 | 8/ 8/60<br>6/ 1/61 | -- | D | PASNY 103; anal. |
| 307-903-1 | De Veaux School | 1961 | Drl | 110 | 8 | 14, 12 | 8 | Sl | 610 | Top of casing | .5 | 50.4 | 10/17/61 | 20 | Dr | Anal.; pumped at 20 gpm with 54 ft dd; T 54 10/17/61; $H_2S$; deepened to 135 ft to connect with sewer tunnel. |
| 308-827-1 | J. Pratt | -- | Drl | 20 | 5 | 6 | 5 | Sl | 640 | Recess in tile | .7 | 10.8 | 9/28/61 | -- | D | inadequate summer 1960. |
| 308-836-1 | C. Walker | -- | Drl | 22 | -- | 6 | -- | Sl | 605 | Top of coupling | 1.6 | 1.3 | 8/23/61 | -- | D | |

Table 7.--Records of selected wells in the Niagara Falls area (Continued)

| Well number | Owner | Year completed | Type of well | Depth of well (feet) | Depth of casing (feet) | Diameter (inches) | Depth to bedrock (feet) | Water-bearing material | Altitude above sea level (feet) | Measuring point: Description | Measuring point: Position | Water level: Below land surface (feet) | Water level: Date | Yield (gallons per minute) | Use | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 308-841-1 | J. Smith | -- | Drl | 48 | r16 | 6 | r16 | Sl | 615 | Top of casing | 0.6 | 2.3 | 8/16/61 | b10 | D | Cl 13 8/16/61; $H_2S$. |
| -2 | G. Gill | 1954 | Drl | 21 | -- | 6 | -- | Sl | 615 | do. | .7 | 4.8 | 8/16/61 | -- | D | Cl 31 8/16/61; $H_2S$. |
| -4 | J. Molinson | 1956 | Drl | 30 | r10 | 6 | r10 | Sl | 600 | do. | 1.0 | 1.8 | 8/16/61 | b>40 | D | Cl 31 8/16/61. |
| 308-846-1 | A. Stahl | -- | Drl | 43 | -- | 6 | -- | Sl | 610 | do. | .3 | p11.3 | 6/13/61 | -- | D | |
| -2 | do. | -- | Drl | 37 | -- | 6 | -- | Sl | 610 | do. | .8 | 3.5 | 6/13/61 | -- | S | |
| 308-847-1 | M. Drinkwalter | 1961 | Drl | 48 | -- | 6 | r3 | Sl | 620 | do. | .8 | 3.8 | 6/13/61 | -- | D | Cl 12.5 6/13/61; $H_2S$. |
| -2 | R. Austin | 1956 | Drl | 41 | -- | 6 | r5 | Sl | 620 | do. | 1.1 | 3.9 | 6/13/61 | -- | D | |
| 308-850-1 | U. S. Air Force | 1949 | Drl | r63 | r10 | 6 | r10 | Sl | s625 | Center of pressure gage | LS | p27.5 | 6/ 8/61 | r>90 | PS | Anal.; pumped at 90 gpm with 3 ft dd; T 52 8/21/59; $H_2S$; pumped with 308-850-2 at combined rate of 50,000 to 70,000 gpd. |
| -2 | do. | 1950 | Drl | r61 | r8 | 6 | r8 | Sl | s623 | do. | LS | p33 | 6/ 8/61 | r>82 | PS | Anal.; pumped at 82 gpm with slight dd; T 52 7/21/59; $H_2S$; see remarks for 308-850-1. |
| 308-851-1 | E. Krull | 1958 | Drl | 43 | -- | 6 | -- | Sl | 630 | Top of casing | 1.5 | 7.7 | 6/13/61 | b3 | D | $H_2S$. |
| -2 | A. Mueller | 1961 | Drl | 34 | 15 | 6 | 16 | Qsg, Sl | 615 | do. | 1.5 | 5.0 | 6/13/61 | b46 | D | Log; T 54.5 8/13/61; aquifer is gravel at top of rock. |
| 308-853-1 | W. Buetel | 1949 | Drl | 27 | r9 | 6 | r9 | Sl | 640 | do. | LS | 10.5 | 9/ 9/60 | r0-50 | D | Seasonal variation in yield; when water-bearing zone 17 ft below LS is dewatered during dry summers, yield is inadequate. |
| -3 | G. Goodheart | 1955 | Drl | 61 | r11 | 6 | r11 | Sl | 650 | do. | .6 | 17.7 | 10/27/60 | b15 | D | |
| -4 | H. Walker | 1955 | Drl | 35 | r4 | 6 | r4 | Sl | 650 | do. | .3 | 15.3 | 10/27/60 | b25 | D | Cl 38 10/27/60. |
| 308-854-1 | W. Kroening | -- | Drl | 38 | -- | 6 | r11 | Sl | 630 | do. | .5 | 23.1 | 10/27/60 | -- | D, S | Cl 85 10/27/60. |
| 308-856-1 | N. Hasley | -- | Dug, Drl | 38 | -- | -, 6 | -, r6 | Sl | 640 | Top of concrete floor | .5 | 27.9 | 10/27/60 | -- | D | Cl 14.5 10/27/60. |
| 308-857-1 | F. Scholefield | -- | Drl | 38 | -- | 6 | -- | Sl | 630 | Top of casing | .3 | 13.4 | 8/ 7/60 | -- | D, U | Inadequate. |
| -2 | A. Wittcopp | 1957 | Drl | 34 | -- | 6 | -- | Sl | 640 | do. | .6 | 25.6 | 10/27/60 | -- | D | |
| 308-858-1 | Colonial Village School | 1949 | Drl | 37 | r11 | 6 | r11 | Sl | s629 | do. | 1.0 | 20.8 | 8/ 8/60 | b20 | I, U | |
| -2 | E. Heath | -- | Drl | 44 | -- | 6 | -- | Sl | s638 | do. | .2 | 25.1 | 8/ 7/60 | -- | D | |
| -3 | W. Holland | -- | Drl | 49 | -- | 6 | -- | Sl | s629 | Top of coupling | .4 | 12.0 | 8/ 8/60 | -- | D | $H_2S$. |
| -4 | P. Wagner | 1957 | Drl | 33 | r13 | 6 | r13 | Sl | 630 | Top of casing | 1.2 | g16.5 | 11/ 2/61 | b>20 | D | $H_2S$. |
| -5 | Niagara Mohawk Power Corp. | -- | Drl | 45 | 6 | 6 | 6 | Sl | s634 | do. | 3.3 | F,g17.1<br>h13.4 | 10/26/61<br>11/15/62 | b>45 | D, O | PASNY OW 178. |
| -6 | PASNY | 1961 | Drl | 61 | 10 | 6 | 10 | Sl | s621 | do. | 4.1 | F,h1.0 | 11/15/62 | b30+ | O, PR | PASNY OW 193. |
| -7 | do. | 1962 | Drl | 61 | 10 | 6 | 10 | Sl | s623 | do. | 3.1 | F,h2.6 | 11/15/62 | b30+ | O, PR | PASNY OW 209. |
| 308-859-1 | Niagara Mohawk Power Corp. | 1958 | Drl | 65 | 11 | 6 | 11 | Sl | s606 | do. | 3.4 | F,c37.1<br>g26.1<br>h20.0 | 10/ 1/60<br>10/26/61<br>11/15/62 | -- | O | PASNY OW 104; $H_2S$. |
| -3 | do. | 1958 | Drl | 16 | 12 | 6 | 12 | Sl | s607 | do. | 3.6 | F,g6.5<br>h4.1 | 10/26/61<br>11/15/62 | -- | O | PASNY OW 104B. |
| -4 | do. | 1958 | Drl | 100 | 16 | 6 | 16 | Sl | s611 | do. | 2.9 | F,g10.4<br>h8.4 | 10/26/61<br>11/15/62 | b42 | O | PASNY OW 118; anal.; packer 38 ft below LS; water level below packer g31.8 10/26/61 and h26.0 11/15/62. |

Table 7.--Records of selected wells in the Niagara Falls area (Continued)

| Well number | Owner | Year completed | Type of well | Depth of well (feet) | Depth of casing (feet) | Diameter (inches) | Depth to bedrock (feet) | Water-bearing material | Altitude above sea level (feet) | Measuring point: Description | Measuring point: Position | Water level: Below land surface (feet) | Water level: Date | Yield (gallons per minute) | Use | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 308-859-5 | Niagara Mohawk Power Corp. | 1958 | Drl | 16 | 14 | 2 | 17 | Qtl | s611 | Top of casing | 3.0 | F,g10.3<br>h8.3 | 10/26/61<br>10/30/62 | -- | O | PASNY OW 118A. |
| -6 | do. | 1958 | Drl | 68 | 19 | 6 | 19 | Sl | s614 | do. | 4.0 | F,g14.7<br>h11.7 | 10/26/61<br>11/15/62 | b19 | O | PASNY OW 106; packer 34 ft below LS; water level below packer g38.9 10/26/61 and h33.3 11/15/62. |
| -8 | PASNY | 1959 | Drl | 98 | 21 | 6 | 21 | Sl | s610 | do. | 3.0 | F,g9.2<br>h6.5 | 10/26/61<br>11/15/62 | b11 | O | PASNY OW 127; packer 36 ft below LS; water level below packer g30.6 10/26/61 and h22.2 11/15/62; $H_2S$. |
| -9 | do. | 1959 | Drl | 11 | 8 | 2 | 11 | Qtl | s610 | do. | 3.0 | F,g8.5<br>h9.8 | 10/26/61<br>10/30/62 | -- | O | PASNY OW 128A. |
| -10 | -- | 1959 | Drl | 100 | 12 | 6 | 12 | Sl | s610 | do. | 3.1 | F,g8.6<br>h6.0 | 10/26/61<br>11/15/62 | b47 | O | PASNY OW 128; packer 33 ft below LS; water level below packer g28.8 10/26/61 and h22.9 11/15/62; $H_2S$. |
| -11 | -- | 1959 | Drl | 74 | 15 | 6 | 15 | Sl | s612 | do. | 3.0 | F,g10.3<br>h7.7 | 10/26/61<br>11/15/62 | b51 | O | PASNY OW 129; packer 35 ft below LS; water level below packer g30.4 10/26/61 and h24.6 11/15/62. |
| -13 | J. Williams | 1948 | Drl | 24 | a22 | 6 | a22 | Sl | s613 | Top of breather pipe | .5 | 15.8 | 8/ 8/60 | b >25 | D | |
| 308-900-1 | PASNY | 1959 | Drl | 101 | 15 | 6 | 15 | Sl | s613 | Top of casing | 2.6 | F,g15.4<br>h7.6 | 10/26/61<br>11/15/62 | b24 | O | PASNY OW 121; packer 58 ft below LS; water level below packer g56.5 10/26/61 and h57.6 11/15/62; lower water level affected by PASNY conduits. |
| -3 | do. | 1959 | Drl | 100 | 11 | 6 | 11 | Sl | s613 | do.<br>Top of casing extension | 2.9<br>10.1 | F,g15.5<br>h+1.5 | 10/26/61<br>11/15/62 | b31 | O | PASNY OW 122; packer 51 ft below LS; water level below packer g54.2 10/26/61 and h49.2 11/15/62; lower water level affected by PASNY conduits; $H_2S$. |
| -5 | do. | 1959 | Drl | 76 | 11 | 6 | 11 | Sl | s607 | Top of casing | 3.2 | F,g12.9<br>h4.8 | 10/26/61<br>11/15/62 | -- | O | PASNY OW 120; packer 23 ft below LS; water level below packer g14.4 10/26/61 and h5.6 11/15/62; packer may be ineffective. |
| -7 | do. | 1959 | Drl | 100 | 12 | 6 | 12 | Sl | s608 | do.<br>Top of casing extension | 2.7<br>5.9 | F,g7.5<br>h+.4 | 10/26/61<br>11/15/62 | b39 | O | PASNY OW 124; packer 35 ft below LS; water level below packer g28.8 10/26/61 and h32.3 11/15/62; water level below packer affected by PASNY conduits. |
| -9 | Niagara Falls Memorial Park | 1959 | Drl | 100 | 14 | 6 | 14 | Sl | s610 | Top of casing | 2.5 | F,g14.2<br>h8.6 | 10/26/61<br>11/15/62 | b36 | O | PASNY OW 125; packer 34 ft below LS; water level below packer g33.7 10/26/61 and h30.0 11/15/62; lower water level affected by PASNY conduits; $H_2S$. |
| -11 | -- | 1959 | Drl | 72 | 8 | 6 | 8 | Sl | s599 | do. | 2.9 | F,g7.5<br>h5.3 | 10/26/61<br>11/15/62 | b39 | O | PASNY OW 126; packer 22 ft below LS; water level below packer g16.1 10/26/61 and h15.1 11/15/62; water levels affected by Gill Creek; $H_2S$. |
| -13 | G. Ball | 1950 | Drl | 19 | r14 | 6 | r14 | Sl | s605 | do. | .8 | 12.5 | 8/ 8/60 | b30 | D | Inadequate. |
| -14 | PASNY | 1961 | Aug | 10 | 9 | 6 | 12 | Qtl | s613 | do. | 4.2 | F,g9.2<br>h6.5 | 11/14/61<br>9/13/62 | -- | O | PASNY OW 179; log. |
| -15 | do. | -- | Drl | 29 | 12 | 6 | 12 | Sl | s613 | do.<br>Top of casing extension | 3.5<br>6.1 | F,g4.1<br>h+.6 | 11/22/61<br>3/14/62 | b17 | D, O | PASNY OW 180; pt; pumped at 5.5 gpm with 6.7 ft dd; $H_2S$. |
| -16 | do. | 1961 | Drl | 47 | 11 | 6 | 6 | Sl | 610 | Top of casing | 11.0 | h+7.0 | 11/15/62 | b20 | O, PR | PASNY OW 182; anal.; flows at 3.2 gpm with dd of 3.5 ft; rate of flow varies depending upon stage of PASNY reservoir; T 50.0 12/13/61; $H_2S$. |
| -17 | do. | 1961 | Drl | 50 | 11 | 6 | 11 | Sl | s610 | Top of coupling | 5.0 | F,h7.3 | 11/15/62 | b>30 | O, PR | PASNY OW 184; water level varies with stage of PASNY reservoir. |
| -18 | do. | 1961 | Drl | 46 | 14 | 6 | 14 | Sl | s608 | Top of casing | 3.2 | F,h5.1 | 3/14/62 | b>30 | O, PR | PASNY OW 183; water level varies with stage of PASNY reservoir. |
| -19 | do. | 1961 | Drl | 50 | 11 | 6 | 11 | Sl | s613 | -- | -- | h+2.2 | 11/15/62 | -- | O, PR | PASNY OW 204; anal.; flows at 0.5 to 11 gpm (at 2 ft above LS) depending upon stage of PASNY reservoir; T 51.8 5/14/62. |
| -20 | do. | 1961 | Drl | 55 | 14 | 6 | 14 | Sl | s613 | -- | -- | h+.6 | 11/15/62 | b>30 | O, PR | PASNY OW 190; anal.; flows at 0 to 4.5 gpm (at 1.2 ft above LS) depending upon stage of PASNY reservoir; T 52.0 5/14/62. |

Table 7.--Records of selected wells in the Niagara Falls area (Continued)

| Well number | Owner | Year completed | Type of well | Depth of well (feet) | Depth of casing (feet) | Diameter (inches) | Depth to bedrock (feet) | Water-bearing material | Altitude above sea level (feet) | Measuring point: Description | Measuring point: Position | Water level: Below land surface (feet) | Water level: Date | Yield (gallons per minute) | Use | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 308-900-21 | PASNY | 1961 | Drl | 50 | 12 | 6 | 12 | Sl | s612 | Top of casing | 4.8 | F,h+0.8 | 11/15/62 | b>30 | O, PR | PASNY OW 189; water level varies with stage of PASNY reservoir. |
| 308-901-1 | do. | 1960 | Aug | 6 | 4 | 2 | -- | Qtl | s618 | do. | 3.0 | F,g5.4 | 8/10/60 | -- | O | PASNY WP 124; well destroyed prior to flooding of PASNY reservoir. |
| -3 | do. | 1960 | Aug | 6 | 4 | 2 | -- | Qtl | s618 | do. | 2.5 | F,g5.3 | 8/10/60 | -- | O | PASNY WP 109; well destroyed prior to flooding of PASNY reservoir. |
| -6 | Stauffer Chemical Co. | 1944 | Drl | 168 | r15 | 8 | r15 | Sl, Sc | 610 | do. | LS | 23.3 | 8/23/60 | r40-50 | I, A | $H_2S$; inadequate. |
| -7 | PASNY | 1961 | Drl | 60 | 18 | 6 | 18 | Sl | s619 | do. | 2.7 | F,h6.7 | 3/14/62 | b50 | O, PR | PASNY OW 181; water level varies with stage of PASNY reservoir. |
| -8 | do. | 1961 | Drl | 60 | 6 | 6 | 6 | Sl | s621 | do. | 3.5 | F,h14.4 | 11/15/62 | b10 | O, PR | PASNY OW 186; water level varies with stage of PASNY reservoir. |
| -9 | do. | 1961 | Drl | 60 | 10 | 6 | 10 | Sl | s618 | do. | 1.2 | F,h20.3 | 11/15/62 | b<1 | O, PR | PASNY OW 185; water level varies with stage of PASNY reservoir. |
| -10 | do. | 1961 | Drl | 53 | 12 | 6 | 12 | Sl | s615 | do. | 3.8 | F,h3.0 | 11/15/62 | b30+ | O, PR | PASNY OW 201; yield of well exceeded bailing capacity. |
| 308-902-1 | J. O'Connor | -- | Dug | 6 | -- | 36 | -- | Qd | 590 | -- | LS | .5 | 8/25/60 | >2 | D | Anal.; flowing 2.0 gpm at 0.5 ft below LS 8/25/60. |
| -2 | PASNY | 1960 | Drl | 98 | -- | 6 | -- | Sl | s595 | Top of casing | 3.1 | F,d31.6 | 5/31/61 | -- | O | PASNY OW 175. |
| -3 | do. | 1961 | Drl | 100 | 10 | 6 | 10 | Sl | s585 | do. | 3.2 | F,d48.0 | 5/31/61 | -- | O | PASNY OW 176; |
| -4 | do. | 1961 | Drl | 100 | -- | 6 | -- | Sl | s588 | do. | 4.3 | F,d37.5 | 1/18/61 | -- | O | PASNY OW 173. |
| -5 | do. | 1961 | Drl | 85 | -- | 6 | -- | Sl | s566 | do. | 4.6 | F,d70.3 | 1/18/61 | -- | O | PASNY OW 172; log. |
| -6 | do. | 1961 | Drl | 117 | 25 | 3 | 25 | Sl | 585 | do. | 3.0 | d53.7 | 1/16/61 | -- | T, O | PASNY OW 174; log; well drilled at 70° angle, measurements converted to vertical. |
| -7 | Stauffer Chemical Co. | -- | Drl | r172 | r15 | r8 | r15 | Sl | 610 | -- | -- | -- | -- | r<40 | I, A | |
| 309-820-1 | H. Dennis | -- | Dug | 22 | -- | a48 | -- | Qtl | 665 | Top of well cover | LS | 14.9 | 10/26/61 | -- | D | Cl 180 10/26/61; reported adequate for five families during dry years. |
| -2 | H. Wilson | -- | Dug | 30 | -- | a36 | -- | Qtl | 665 | Top of stone slabs | LS | 13.1 | 10/26/61 | -- | D, A | |
| 309-824-1 | R. Bedford | -- | Drl | a44 | -- | 6 | -- | Qsg | 660 | Top of casing | -4.0 | p29.2 | 10/20/61 | -- | D | |
| 309-826-1 | R. Shaal | -- | Dug | 12 | -- | a30 | -- | Qsg | 640 | Top of well cover | .5 | 9.9 | 9/28/61 | -- | D | |
| 309-829-1 | R. Brown | -- | Dug | 20 | -- | a36 | -- | Qtl | 635 | Top of breather pipe | .2 | 10.2 | 9/28/61 | -- | D | |
| 309-832-1 | W. Spielberger | -- | Dug | 17 | -- | 30 | -- | Qtl | 640 | Top of wooden cover | LS | 9.4 | 9/14/61 | -- | D, U | |
| 309-833-1 | B. Spielberger | -- | Dug | 23 | -- | 24 | -- | Qtl | 640 | Recess for well cover | 2.0 | 9.4 | 9/14/61 | -- | D, U | |
| -2 | do. | -- | Dug | 29 | -- | 30 | -- | Qtl | 640 | Recess in concrete curbing | .2 | 13.9 | 9/14/61 | -- | D, S | |
| 309-837-1 | H. Merchant | 1954 | Drl | 29 | r10 | 6 | r10 | Sl | 630 | Top of casing | .6 | 8.3 | 8/23/61 | -- | D | Cl 22 8/23/61; inadequate August-November. |
| -2 | do. | -- | Dug, Drl | 26 | -- | 30, 6 | a17 | Qtl, Sl | 630 | Concrete floor | LS | 10.0 | 8/23/61 | -- | D, S | Inadequate August-November. |
| -3 | do. | -- | Drl | 34 | a17 | 5 | a17 | Sl | 630 | Top of casing | LS | 8.4 | 8/23/61 | -- | S | Used when 309-837-1 and 309-837-2 are inadequate. |
| 309-844-1 | T. Downer | 1952 | Drl | 21 | -- | 6 | -- | Sl | 610 | do. | .5 | 3.7 | 6/13/61 | -- | D | |
| 309-848-1 | W. Comer | 1960 | Drl | 50 | r9 | 6 | r9 | Sl | 635 | do. | 1.0 | 6.8 | 6/13/61 | b10 | D | $H_2S$. |
| 309-850-1 | U. S. Army | -- | Drl | r40 | a16 | r8 | r16 | Sl | 630 | -- | -- | -- | -- | r60 | PS | Anal.; pumped at 60 gpm with 13 ft dd. |

Table 7.--Records of selected wells in the Niagara Falls area (Continued)

| Well number | Owner | Year com-ple-ted | Type of well | Depth of well (feet) | Depth of casing (feet) | Diameter (inches) | Depth to bedrock (feet) | Water-bearing material | Altitude above sea level (feet) | Measuring point: Description | Measuring point: Position | Water level: Below land surface (feet) | Water level: Date | Yield (gallons per minute) | Use | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 309-850-2 | U. S. Army | 1955 | Drl | r43 | r23 | -- | r22 | Sl | 640 | -- | LS | r20 | -- | b35 | PS | Anal.; inadequate. |
| 309-853-1 | G. Wienke | -- | Drl | 28 | r21 | 6 | r21 | Sl | 640 | Top of casing | 0.7 | 21.1 | 10/27/60 | b16 | D | |
| -2 | C. Fraser | 1954 | Drl | 31 | r11 | 6 | r11 | Sl | 640 | do. | 1.8 | 16.5 | 10/28/60 | b>20 | D | Cl 115 10/28/60. |
| -3 | N. Wendt | -- | Drl | 28 | a3 | 6 | 3 | Sl | 660 | do. | 1.5 | 13.4 | 10/28/60 | r110 | D, PS | Used as emergency supply by local fire companies. |
| 309-856-1 | M. Printup | 1960 | Drl | 48 | r4 | 6 | r2 | Sl | 640 | do. | .3 | 23.7 | 9/10/60 | b13 | D | Bailed at 13 gpm with 16 ft dd. |
| -2 | V. Printup | 1959 | Drl | 62 | r6 | 6 | r6 | Sl | 640 | do. | 1.2 | 16.0 | 9/13/60 | b4 | PS | Used together with wells 309-856-3 and 309-856-5 to supply trailer camp of 112 persons. |
| -3 | do. | 1959 | Drl | 28 | r5 | 8 | r5 | Sl | 640 | do. | .5 | 13.1 | 9/13/60 | b14 | PS | |
| -4 | do. | 1959 | Drl | 71 | r7 | 8 | r7 | Sl | 640 | do. | .7 | 15.7 | 9/13/60 | b1 | PS, U | Inadequate. |
| -5 | do. | 1958 | Drl | r22 | r7 | 8 | r7 | Sl | 640 | do. | LS | 14.4 | 9/13/60 | b20 | PS | Anal. |
| -6 | J. Ligammari | 1956 | Drl | 31 | r10 | 6 | r10 | Sl | 640 | do. | LS | 20.1 | 10/27/60 | r0-40 | D | Seasonal variation in yield; inadequate in fall of 1960. |
| 309-857-1 | L. Henry | -- | Drl | 27 | -- | 6 | -- | Sl | 630 | do. | 1.1 | 11.5 | 9/13/60 | -- | D | |
| -2 | B. Farnham | 1960 | Drl | 83 | a4 | 6 | r4 | Sl | 650 | do. | .8 | p39.8 | 10/21/60 | b4 | D | Bailed at 4 gpm with 38 ft dd. |
| 309-858-1 | H. Henry | -- | Drl | 29 | -- | 6 | -- | Sl | 640 | Top of coupling | .7 | 18.5 | 9/13/60 | -- | D | Anal.; T 56 9/13/60. |
| -2 | E. Mt. Pleasant | 1945 | Drl | 20 | -- | 6 | a8 | Sl | 620 | Top of casing | .8 | g8.1 | 10/21/60 | b>25 | D, U | $H_2S$. |
| -3 | PASNY | 1961 | Drl | 60 | 6 | 6 | 6 | Sl | s620 | do. | 3.2 | h+1.3 | 11/15/62 | -- | O, PR | PASNY OW 206; anal.; flows at 14 gpm with 0.3 ft dd; rate of flow at LS varies depending upon stage of PASNY reservoir; T 45.3 5/14/62; $H_2S$. |
| -4 | do. | 1961 | Drl | 15 | 6 | 6 | 6 | Sl | s621 | do. | 3.2 | h+1.7 | 11/15/62 | -- | O, PR | PASNY OW 205; anal.; flows at 13 to 33 gpm at LS depending upon stage of PASNY reservoir; T 44.2 5/14/62; $H_2S$. |
| -5 | do. | 1961 | Drl | 50 | 10 | 3 | 10 | Sl | s610 | do. | 3.2 | F,h.9 | 11/15/62 | -- | O, PR | PASNY OW 188. |
| 309-859-1 | N. Scott | 1959 | Drl | 70 | 7 | 6 | 7 | Sl | s612 | do.<br>Top of casing extension | 3.2<br>5.1 | F,g4.6<br>h+.9 | 10/26/61<br>11/14/62 | 4 | O | PASNY OW 107; log; anal.; pt; water level varies with stage of PASNY reservoir; pumped at 2.2 gpm with 8.2 ft dd; salty. |
| -2 | do. | 1959 | Drl | 70 | 11 | 6 | 11 | Sl | s614 | Top of casing<br>Top of casing extension | 3.4<br>6.0 | F,g5.5<br>h2.5 | 10/26/61<br>11/14/62 | 3 | O | PASNY OW 108; log; anal.; pt; pumped at 2.2 gpm with 13.3 ft dd; $H_2S$; salty. |
| -3 | do. | 1959 | Drl | 61 | 12 | 6 | 12 | Sl | s618 | Top of casing | 2.8 | F,g9.6<br>h4.6 | 10/26/61<br>11/14/62 | b1 | O | PASNY OW 109; anal.; T 50.5 5/14/62. |
| -4 | do. | 1959 | Drl | 112 | 12 | 6 | 12 | Sl | s628 | do. | 3.1 | F,g10.7<br>h6.7 | 10/26/61<br>11/14/62 | b<1 | O | PASNY OW 110; log; |
| -6 | PASNY | 1959 | Drl | 12 | 9 | 2 | 12 | Qd | 620 | do. | 3.0 | g2.1 | 7/12/60 | -- | O, De | PASNY WP 202; well destroyed prior to flooding of PASNY reservoir. |
| -9 | do. | 1959 | Drl | 14 | 11 | 2 | 15 | Qd | 625 | do. | 3.0 | g6.6 | 7/12/60 | -- | O, De | PASNY WP 200; well destroyed prior to flooding of PASNY reservoir. |
| -10 | E. Zomont | 1960 | Drl | 42 | r11 | 6 | r11 | Sl | 625 | do. | 1.0 | 16.8 | 8/23/60 | b15 | PS | Adequate for trailer court with nine families. |
| -11 | PASNY | -- | Drl | 54 | -- | 6 | -- | Sl | 630 | do. | .7 | g14.3 | 9/27/60 | -- | D, De | Well destroyed prior to flooding of PASNY reservoir. |
| -12 | do. | 1961 | Drl | 52 | 10 | 3 | 10 | Sl | s618 | -- | -- | F,h2.3 | 11/15/62 | -- | O, PR | PASNY OW 187, log; flows at 0 to 0.2 gpm depending upon stage of PASNY reservoir. |
| 309-900-1 | do. | 1959 | Drl | 88 | 8 | 6 | 8 | Sl | s625 | Top of casing | 3.4 | F,g11.9<br>h1.4 | 10/26/61<br>11/15/62 | b16 | O | PASNY OW 111; packer 32 ft below LS; water level below packer g36.5 10/26/61 and h33.3 11/15/62. |

Table 7.--Records of selected wells in the Niagara Falls area (Continued)

| Well number | Owner | Year completed | Type of well | Depth of well (feet) | Depth of casing (feet) | Diameter (inches) | Depth to bedrock (feet) | Water-bearing material | Altitude above sea level (feet) | Measuring point: Description | Measuring point: Position | Water level: Below land surface (feet) | Water level: Date | Yield (gallons per minute) | Use | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 309-900-3 | -- | 1959 | Drl | 87 | 9 | 6 | 9 | Sl | s624 | Top of casing | 3.3 | F,g15.7<br>h5.2 | 10/26/61<br>11/15/62 | b42 | O | PASNY OW 112; packer 29 ft below LS; water level below packer g27.4 10/26/61 and h22.6 11/15/62. |
| -5 | -- | 1959 | Drl | 77 | 9 | 6 | 9 | Sl | s601 | do. | 3.0 | F,g4.6<br>h.2 | 10/26/61<br>11/15/62 | b7 | O | PASNY OW 113; log; packer 31 ft below LS; water level below packer g13.6 10/26/61 and h8.2 11/15/62. |
| -6 | -- | 1959 | Drl | 8 | 6 | 2 | 8 | Qtl | s601 | do. | 3.2 | F,g6.3<br>h3.4 | 10/26/61<br>10/30/62 | -- | O | PASNY OW 113A. |
| -7 | E. Panozzo | 1949 | Drl | 29 | r7 | 6 | r7 | Sl | 620 | Top of well cap | 1.2 | 10.4 | 8/ 8/60 | -- | D | PASNY R 13; $H_2S$. |
| -8 | PASNY | 1961 | Aug | 9 | 8 | 6 | 9 | Qtl | s609 | Top of casing | 3.0 | F,g5.9<br>h8.5 | 10/26/61<br>9/14/62 | -- | O | PASNY OW 177; log; pt. |
| -9 | do. | 1961 | Drl | 59 | 8 | 6 | 8 | Sl | s607 | -- | -- | h+.6 | 11/14/62 | -- | O, PR | PASNY OW 196; anal.; flows at 2 to 10 gpm depending upon stage of PASNY reservoir; T 48.5 5/14/62; $H_2S$. |
| 309-901-1 | do. | 1959 | Drl | 89 | 8 | 6 | 8 | Sl | s625 | Top of casing | 3.4 | F,g7.2<br>h3.3 | 10/26/61<br>11/15/62 | -- | O | PASNY OW 115; log; packer 30 ft below LS; water level below packer g48.9 10/26/61 and h44.7 11/15/62. |
| -2 | do. | 1959 | Drl | 8 | 5 | 2 | 8 | Qtl | s625 | do. | 3.4 | F,g5.9<br>h3.7 | 10/26/61<br>10/30/62 | -- | O | PASNY OW 115A. |
| -3 | Niagara Mohawk Power Corp. | 1959 | Drl | 87 | 7 | 6 | 7 | Sl | s623 | do. | 3.5 | F,g12.4<br>h7.5 | 10/26/61<br>11/15/62 | b8 | O | PASNY OW 116; log; packer 35 ft below LS; water level below packer g45.5 10/26/61 and h41.5 11/15/62. |
| -5 | do. | 1959 | Drl | 90 | 8 | 6 | 8 | Sl | s621 | do. | 3.0 | F,g16.7<br>h12.5 | 10/26/61<br>11/15/62 | b39 | O | PASNY OW 117; packer 30 ft below LS; water level below packer g42.3 10/26/61 and h38.4 11/15/62. |
| -7 | -- | 1959 | Drl | 111 | 10 | 6 | 10 | Sl | s602 | do. | 2.9 | F,g16.1<br>h11.1 | 10/26/61<br>11/14/62 | b<1 | O | PASNY OW 123; log; anal.; T 49.0 5/14/62; natural gas. |
| -9 | -- | 1959 | Drl | 70 | 8 | 6 | 7 | Sl | s598 | do. | 2.5 | F,g1.2<br>h+.4 | 10/26/61<br>11/15/62 | -- | O | PASNY OW 114; log; packer 28 ft below LS; water level below packer g10.2 10/26/61 and h7.4 11/15/62; $H_2S$. |
| 310-821-1 | H. McPherson | -- | Drl | 25 | -- | 6 | -- | Qsg | 650 | do. | 1.2 | 13.1 | 11/ 7/61 | -- | D | |
| 310-826-1 | C. Caleb | 1954 | Drl | r48 | -- | 6 | r48 | Qsg | 660 | -- | -- | -- | -- | -- | D | |
| -2 | F. Mietz | -- | Dug | 12 | -- | a30 | -- | Qsg | 630 | Top of well cover | LS | 9.9 | 10/20/61 | -- | D | |
| -3 | do. | 1958 | Drl | 48 | -- | 6 | -- | Qsg | 630 | Top of casing | 1.6 | 7.9 | 10/20/61 | -- | D, S | $H_2S$; aquifer is probably gravel at top of bedrock. |
| 310-843-1 | R. Shorers | 1961 | Drl | 29 | r5 | 6 | r5 | Sa | 500 | do. | 1.8 | 13.9 | 8/16/61 | -- | D | |
| -2 | -- | 1961 | Drl | r38 | r2 | 6 | r2 | Sa | 500 | -- | -- | -- | -- | b4 | D | |
| 310-844-1 | W. Greenman | -- | Drl | 46 | -- | 6 | -- | Sl | 640 | Top of casing | 1.0 | 23.5 | 6/ 8/61 | b8 | D | Inadequate in fall of 1960. |
| 310-845-1 | B. Lovell | 1940 | Drl | 34 | -- | 6 | -- | Sl | 640 | Top of curbing | 1.0 | 15.0 | 6/ 8/61 | -- | D | |
| -2 | C. Dethlefs | 1948 | Drl | 40 | -- | 6 | -- | Sl | 635 | Top of casing | LS | 16.6 | 6/ 8/61 | -- | D | Inadequate in fall of 1960. |
| 310-852-1 | W. Strausberg | 1956 | Drl | 40 | 4 | 6 | 4 | Sl | 635 | do. | .5 | 7.4 | 10/ 1/61 | b7 | D | $H_2S$. |
| 310-853-1 | G. Lewandowski | 1958 | Drl | 57 | -- | 6 | -- | Sc, Sa | 540 | do. | .4 | 26.2 | 10/28/60 | b2 | D | Anal.; salty. |
| -2 | L. Cindric | 1949 | Drl | 28 | -- | 6 | -- | Sc | 535 | do. | 1.0 | 13.5 | 10/28/60 | -- | D | |
| 310-854-1 | J. Printup | -- | Drl | 62 | r11 | 6 | r11 | Sl | 650 | do. | .9 | 27.8 | 10/27/60 | b13 | PS | Log; Cl 47 10/27/60; adequate for trailer court with seven families. |
| -2 | do. | -- | Drl | 46 | r11 | 6 | r11 | Sl | 650 | do. | LS | 26.1 | 10/27/60 | b3 | D | Inadequate to supply trailer court; replaced by well 310-854-1. |
| -3 | do. | -- | Dug | 19 | -- | 36 | r19 | Qtl | 650 | Top of well cover | LS | 13.0 | 10/27/60 | -- | D, U | |

Table 7.--Records of selected wells in the Niagara Falls area (Continued)

| Well number | Owner | Year com-ple-ted | Type of well | Depth of well (feet) | Depth of casing (feet) | Diameter (inches) | Depth to bedrock (feet) | Water-bearing material | Altitude above sea level (feet) | Measuring point | | Water level | | Yield (gallons per minute) | Use | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Description | Position | Below land surface (feet) | Date | | | |
| 310-854-4 | R. Heinze | -- | Dri | 61 | -- | 6 | -- | Sa | 540 | Top of casing | 1.3 | 46.2 | 10/28/60 | b1 | D | Anal.; salty; inadequate. |
| 310-855-1 | S. Thomes | -- | Drl | 17 | -- | 4 | -- | Sl | 655 | do. | .4 | 10.6 | 10/27/60 | -- | D | Cl 10.5 10/27/60; adequate for one family only. |
| 310-856-1 | H. Patterson | 1960 | Dri | 82 | r3 | 6 | 3 | Sl, Sc | 650 | do. | 2.0 | 50.8 | 10/21/60 | b1 | D, U | $H_2S$. |
| -2 | do. | 1960 | Dri | r55 | r3 | 6 | r3 | Sl | 650 | -- | LS | r17.1 | 11/16/60 | b15 | D | |
| -3 | F. Rickard | 1961 | Drl | 52 | 9 | 6 | 9 | Sl | 655 | Top of casing | 1.8 | 7.0 | 6/ 7/61 | b4 | D | Log; Cl 17 6/7/61; bailed at 4 gpm with 39 ft dd; T 52.5 6/7/61. |
| 310-857-1 | L. Howell | 1955 | Drl | 83 | r22 | 6 | r22 | Oq | 430 | do. | 1.5 | 37.8 | 9/13/60 | b2 | D | Salty. |
| 310-858-2 | J. Proietti | 1959 | Dri | r125 | r101 | 6 | r101 | Oq | 420 | do. | 3.0 | 69.2 | 9/13/60 | -- | D, U | Do. |
| -3 | D. Hibbard | 1959 | Drl | 112 | r100 | 6 | r100 | Oq | 420 | do. | .7 | 66.3 | 9/13/60 | b6 | D | |
| 310-859-1 | C. Johnson | 1960 | Drl | 113 | 43 | 6 | 43 | Sc, Sa | 570 | do. | 1.0 | 18.9 | 8/23/60 | b5 | D | Anal. |
| -3 | D. Mueller | -- | Drl | 62 | -- | 6 | -- | Oq | 370 | do. | LS | 33.4 | 8/25/60 | -- | D | Anal.; salty. |
| -4 | B. Jakubczyk | -- | Dug | 23 | -- | 30 | -- | Qd | 420 | Bottom of well cover | LS | 3.7 | 8/25/60 | -- | D, U | Anal. |
| -5 | do. | 1959 | Drl | r114 | r98 | 6 | r98 | Oq | 420 | -- | LS | Flowing | 8/25/60 | b2 | D | Log; anal.; salty; flows seasonally. |
| -7 | Crouse | 1960 | Drl | 137 | 9 | 6 | 8 | Sa | 520 | Top of casing | 2.0 | 47.2 | 9/ 7/60 | b½ | D | Log; anal.; bailed at ½ gpm with 88 ft dd; $H_2S$; salty. |
| 310-902-1 | W. Blauvelt | 1944 | Drl | r62 | -- | 6 | r18 | Oq | 310 | -- | LS | r40 | -- | -- | C, D | Anal.; water from this well sold commercially as "Brightstone Spring Water." |
| 311-822-1 | Village of Medina | 1905 | Dug | 34 | a10 | 216 x 324 | a10 | Sl | 610 | Opening for hatch cover | 3.0 | 5.2 | 9/28/61 | e >100 | PS, U | Anal.; T 59 9/28/61; combined pumpage with wells 311-822-2 and 311-822-3 varied from 400,000 gpd to 1,000,000 gpd prior to 1960. |
| -2 | do. | 1905 | Dug | 31 | a10 | 216 x 276 | a10 | Sl | 610 | do. | 3.0 | 5.2 | 9/28/61 | e >100 | PS, U | |
| -3 | do. | 1942 | Drl | 43 | -- | 10 | a10 | Sl | 610 | Top of air line | .8 | 6.1 | 9/28/61 | e >100 | PS, U | |
| 311-830-1 | C. Walters | -- | Drl | 31 | -- | 6 | -- | Sl | 620 | Top of well cap | 2.0 | 7.6 | 9/14/61 | -- | D | Cl 25 8/16/61; $H_2S$. |
| -2 | Village of Middleport | 1916 | Dug | 16 | a7 | 780 | a7 | Sl | 615 | Top of curbing | 2.3 | p8.8 | 9/22/61 | e70 | PS | Anal.; average pumping rate 100,000 gpd; inadequate during dry summers. |
| -7 | E. Becker | 1915 | Drl | 34 | 8 | 6 | 8 | Sl | 610 | Top of casing | LS | 5.1 | 9/22/61 | -- | PS, A | One of 6 abandoned public supply wells. |
| -8 | do. | 1915 | Drl | 22 | 8 | 6 | 8 | Sl | 610 | do. | -.2 | 4.9 | 9/22/61 | -- | PS, A | Cl 52 9/22/61; T 54 9/22/61; $H_2S$; one of 6 abandoned public supply wells of identical construction formerly pumped at combined rate of 25,000 gpd. |
| 311-835-1 | Town of Royalton | 1942 | Dug | 17 | 16 | 60 | 16 | Qsg | 520 | Top of tile | .5 | p12.8 | 8/22/61 | -- | PS | Anal.; combined pumpage with well 311-835-2 is 36,000 gpd (average). |
| -2 | do. | 1942 | Dug | 12 | 12 | 60 | -- | Qsg | 520 | do. | .2 | p11.3 | 8/22/61 | -- | PS | Anal. |
| -3 | do. | -- | Drl | 44 | a15 | 6 | a15 | Sc | 520 | Top of casing | .8 | 12.1 | 8/22/61 | -- | T | Abandoned. |
| -4 | do. | -- | Drl | 15 | a15 | 6 | a15 | Qsg or Sc | 520 | do. | .3 | 10.8 | 8/22/61 | -- | T | Do. |
| 311-837-1 | P. Wendel | 1958 | Drl | 61 | -- | 6 | -- | Qsg | s522 | do. | 1.7 | 19.9 | 8/18/61 | -- | D | |
| -2 | L. Wendel | 1959 | Drl | r80 | -- | 6 | r75 | Oq | s525 | -- | -- | -- | -- | b2 | C | |
| -3 | do. | 1961 | Aug | 10 | 7 | 2 | -- | Qsg | s523 | Top of casing | 2.6 | F5.9 | 9/13/61 | -- | O | |
| 311-838-2 | F. Seiler | -- | Dug | 24 | -- | 48 | -- | Qsg | 520 | Top of curbing | -2.5 | p20.6 | 8/17/61 | -- | D | Anal. |

Table 7.--Records of selected wells in the Niagara Falls area (Continued)

| Well number | Owner | Year com- ple- ted | Type of well | Depth of well (feet) | Depth of casing (feet) | Diameter (inches) | Depth to bedrock (feet) | Water-bearing material | Altitude above sea level (feet) | Measuring point: Description | Measuring point: Position | Water level: Below land surface (feet) | Water level: Date | Yield (gallons per minute) | Use | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 311-838-3 | G. Bewley | 1956 | Dug | 17 | -- | 120 x 120 | -- | Qsg | 540 | Recess in concrete cover | 1.0 | 10.7 | 8/17/61 | 200 | PS, U | Constructed to supply proposed Chestnut Heights housing development. |
| 311-839-1 | N. Bertelkamp | -- | Drl | 46 | -- | 6 | -- | Sc? | 560 | Top of casing | 1.0 | 18.3 | 8/17/61 | -- | D | |
| 311-840-1 | R. Nelson | -- | Drl | 63 | a40. | 6 | a40 | Oq | 390 | do. | .6 | 33.7 | 8/16/61 | b15 | D | Cl 95 8/16/61. |
| -2 | J. Nagel | 1960 | Drl | 32 | -- | 6 | -- | Oq? | 390 | do. | 1.0 | 15.2 | 8/16/61 | -- | D | Cl 255 8/16/61. |
| 311-853-1 | H. McQuay | -- | Drl | r114 | r100 | 6 | r100 | Oq | 410 | -- | -- | -- | -- | b5 | D, A | Abandoned because water too salty. |
| 311-854-1 | G. Robinson | 1952 | Drl | 57 | -- | 6 | r40 | Oq | 380 | Top of casing | 1.0 | 20.8 | 11/ 1/60 | -- | D | Cl 16 11/1/60. |
| -2 | C. Battaglia | 1955 | Drl | 64 | r20 | 6 | r20 | Oq | 385 | do. | .3 | 19.0 | 11/ 1/60 | -- | D | Cl 21 11/1/60. |
| 311-855-1 | S. Stacy | 1949 | Drl | 86 | r70 | 6 | r70 | Oq | 400 | do. | .5 | 38.6 | 10/26/60 | b2 | D, A | Abandoned; salty and inadequate. |
| -2 | J. Ullery | -- | Drl | 81 | -- | 6 | -- | Oq | 450 | do. | 1.3 | 40.2 | 10/27/60 | -- | D | Anal.; salty and inadequate. |
| 311-856-1 | G. Mather | 1952 | Drl | 71 | r14 | 6 | r14 | Oq | 420 | do. | 1.4 | 28.4 | 9/13/60 | b>20 | D | |
| 311-858-2 | U. S. Atomic Energy Commission | -- | Dug | 18 | -- | 30 | -- | Qlc | 330 | Top of well cover | .7 | 2.2 | 6/ 8/60 | -- | D, A | |
| -4 | M. Beatty | 1957 | Drl | 58 | r30 | 6 | r30 | Oq | s327 | Top of casing | .6 | p23.9 | 6/10/60 | b5 | D | Salty. |
| 311-859-1 | C. Evans | -- | Dug | 25 | -- | a36 | -- | Qlc | s330 | Recess for well cover | LS | 4.7 | 6/ 9/60 | -- | D | Inadequate. |
| -2 | J. Brownell | 1956 | Drl | 59 | -- | 6 | -- | Oq? | 330 | Top of casing | .8 | 4.4 | 6/ 9/60 | -- | D | |
| -4 | L. Patton | 1947 | Drl | r65 | r21 | 6 | r20 | Oq | 335 | -- | LS | r4 | 6/48 | r1 | D | Well Ni 8 in N. Y. Water Power and Control Comm. Bull. GW-36; anal.; salty. |
| 311-901-1 | A. Szostak | 1954 | Drl | r41 | r41 | 6 | r41 | Qsg | 325 | Top of casing | 1.0 | 8.0 | 6/ 9/60 | b10 | D | Log; aquifer is gravel at top of rock. |
| -2 | W. Kowalczyk | 1954 | Dug | 29 | r29 | 48, 24 | -- | Qls | s325 | Top of well cover | LS | 15.1 | 6/ 9/60 | -- | D, S | Log. |
| 312-840-1 | A. Gloger | -- | Dug | 10 | 10 | 18 | -- | Qsg | 375 | Recess in tile | -6.0 | 7.8 | 9/ 1/61 | -- | D | |
| -2 | do. | -- | Dug | 16 | -- | a24 | -- | Qsg | 375 | Top of well cover | LS | 10.1 | 9/ 1/61 | -- | D | |
| 312-846-1 | R. Harvey | -- | Dug | 15 | 15 | 36 | -- | Qsg | 390 | do. | .5 | 9.8 | 6/15/61 | -- | D | |
| 312-848-1 | P. McTigue | 1959 | Dug | 18 | 18 | 48 | -- | Qsg | 390 | do. | .7 | 12.0 | 6/15/61 | -- | D | |
| 312-849-1 | L. Weber | -- | Dug | 13 | -- | a30 | -- | Qsg | 380 | do. | .5 | 7.7 | 6/16/61 | -- | S, U | |
| -2 | do. | 1867 | Dug | 14 | -- | 30 | -- | Qsg | 380 | do. | .5 | 8.6 | 6/16/61 | -- | C, D | |
| 312-850-1 | J. Lafler | -- | Dug | 15 | 15 | 48 | -- | Qsg | 380 | do. | 2.5 | 8.7 | 6/16/61 | -- | D | Inadequate in fall of 1960. |
| 312-851-1 | L. Allen | 1959 | Dug | 12 | 12 | 60 | -- | Qsg | 390 | do. | .5 | 7.5 | 6/16/61 | -- | D | |
| -2 | R. Townsend | -- | Dug | 12 | -- | a36 | -- | Qsg | 380 | do. | .5 | 8.8 | 6/16/61 | -- | D | |
| 312-852-1 | H. Morgan | 1951 | Drl | 30 | r30 | 6 | r30 | Oq | 365 | Top of breather pipe | .4 | 12.2 | 11/ 8/60 | b16 | D | Slightly salty; aquifer is fractured zone at top of shale. |
| 312-853-1 | C. Ripley | 1955 | Drl | 41 | -- | 6 | -- | Oq | 350 | Top of casing | 1.0 | 11.7 | 11/ 1/60 | -- | D | Anal.; slightly salty. |
| -2 | G. Safarian | -- | Dug | 16 | -- | a30 | -- | Qd | 355 | Top of curbing | .4 | 10.8 | 11/ 1/60 | -- | D, U | |
| -3 | L. Gaul | 1952 | Drl | 77 | r77 | 6 | r77 | Oq | 390 | Top of casing | 2.0 | p28.6 | 11/ 1/60 | -- | D | Anal.; salty; aquifer is fractured zone at top of shale. |
| 312-854-1 | T. Burford | -- | Drl | 35 | -- | 6 | -- | Oq? | 340 | do. | .4 | 7.9 | 11/ 1/60 | -- | D | Cl 220 11/1/60; reported to have flowed in past. |
| 312-857-1 | A. and W. Hayes | 1959 | Drl | 40 | r17 | 6 | r15 | Oq | 325 | do. | .6 | .9 | 6/10/60 | b7 | D | Reported to have flowed in past. |

Table 7.--Records of selected wells in the Niagara Falls area (Continued)

| Well number | Owner | Year com-ple-ted | Type of well | Depth of well (feet) | Depth of casing (feet) | Diameter (inches) | Depth to bedrock (feet) | Water-bearing material | Altitude above sea level (feet) | Measuring point: Description | Measuring point: Position | Water level: Below land surface (feet) | Water level: Date | Yield (gallons per minute) | Use | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 312-857-2 | A. and W. Hayes | 1959 | Dri | 36 | r19 | 6 | r17 | Oq | 325 | Top of casing | 1.3 | 0.3 | 6/10/60 | b7 | D | |
| 312-858-1 | S. Jowdy | -- | Dug | 25 | -- | 27, 18 | -- | Qls | 325 | Top of curbing | .6 | p11.7 | 6/ 8/60 | -- | D | |
| -2 | L. Bowman | -- | Dug, Drl | r38 | -- | 48, 6 | -- | Qd, Oq | 325 | Top of well cover | .4 | 3.3 | 6/10/60 | -- | D | Salty. |
| 312-859-1 | E. Pletcher | -- | Dug | 15 | -- | 36 | -- | Qd | s321 | Top of curbing | LS | 3.6 | 6/ 9/60 | -- | D, A | Anal. |
| -2 | R. Jackson | -- | Drl | r72 | -- | 6 | -- | Oq | 320 | Top of casing | .4 | 7.8 | 6/ 9/60 | -- | D | T 51.0 6/9/60; salty. |
| 312-901-1 | -- | -- | Dug | 29 | -- | 36 | r27 | Qd, Oq | 320 | Top of well cover | LS | p18.9 | 6/ 9/60 | -- | D | inadequate. |
| -2 | -- | -- | Dug | 20 | -- | 24 | -- | Qd | 320 | Top of curbing | LS | 2.6 | 6/ 9/60 | -- | D, U | |
| 313-845-1 | J. Lingle | 1959 | Dug | 16 | 16 | 48 | -- | Qti | 370 | Top of well cover | .5 | p4.2 | 6/15/61 | -- | D | Inadequate. |
| -2 | do. | 1953 | Dug | 20 | 20 | 48 | -- | Qls | 370 | do. | .4 | 1.4 | 6/15/61 | -- | D, U | Do. |
| 313-852-1 | M. Fetterly | -- | Dug | 14 | 14 | 48 | -- | Qls | 350 | Top of curbing | LS | p8.6 | 11/ 8/60 | -- | D | Do. |
| 313-856-1 | W. Robinson | -- | Dug | 29 | -- | a36 | -- | Qd | s321 | Recess in curbing | LS | 8.5 | 6/10/60 | -- | D | Salty; inadequate. |
| -2 | do. | -- | Dug | 28 | -- | 60 | -- | Qd | s319 | Top of well cover | LS | 6.1 | 6/10/60 | -- | S | Salty. |
| 313-857-2 | U. S. Army | -- | Drl | r39 | -- | 8 | r38 | Qsg | 320 | -- | LS | r10.2 | -- | r10 | in | Log; pumped at 10 gpm with 22 ft dd; aquifer is gravel at top of rock. |
| 313-859-1 | R. Cassford | 1938 | Dug, Drl | 48 | -- | 36, 6 | -- | Qd, Oq | 315 | Recess in curbing | .7 | 7.5 | 6/13/60 | -- | D, S | Well Ni 22 in N. Y. Water Power and Control Comm. Bull. GW-36; anal.; T 49.0 6/13/60. |
| -3 | W. Guennel | -- | Dug | 17 | -- | a36 | -- | Qls | 315 | do. | LS | 2.7 | 6/13/60 | -- | S | T 51 6/13/60. |
| 313-901-1 | McNaught | 1960 | Drl | r65 | r64 | 6 | r64 | Qsg | 300 | -- | -- | -- | -- | b25 | D | Log; aquifer is gravel at top of rock. |
| 314-839-1 | F. Strong | -- | Dug | 8 | -- | 60, 30 | -- | Qsg | 395 | Top of well cover | LS | 3.1 | 8/28/61 | -- | S | |
| -2 | do. | -- | Dug | 19 | -- | 36 | -- | Qsg | 400 | do. | .4 | 13.0 | 8/28/61 | -- | D | Inadequate. |
| -3 | do. | 1956 | Dug | 16 | 16 | 42 | -- | Qsg | 400 | do. | .4 | 10.5 | 8/28/61 | -- | D | |
| 314-850-1 | E. Schultz | 1959 | Drl | 91 | r68 | 12 | r68 | Oq | 350 | Top of breather pipe | 1.3 | p27.5 | 8/16/61 | b12 | PS | Cl 195 8/16/61 (sample from wells 314-850-1 and 314-851-1); aquifer is fractured zone at top of shale; combined pumpage with well 314-851-1 estimated at 36,000 gpd. |
| 314-851-1 | do. | 1959 | Drl | r82 | r62 | r12 | r62 | Oq | 350 | -- | -- | -- | -- | b30 | PS | Do. |
| 314-854-1 | H. Ward | -- | Drl | 71 | r40 | 6 | r40 | Oq | 310 | Top of casing | .3 | 8.9 | 11/ 8/60 | b5 | D, U | Salty. |
| 314-857-1 | F. Diez | -- | Dug | 17 | -- | a36 | -- | Qls | s307 | Top of well cover | LS | p6.5 | 6/10/60 | -- | D | |
| -2 | do. | -- | Dug | 21 | -- | -- | -- | Qls | 300 | Floor of pump house | LS | p9.0 | 6/10/60 | -- | S | inadequate in late summer. |
| 314-859-1 | E. Quenneville | 1956 | Drl | 77 | -- | 6 | -- | Oq | 310 | Top of casing | 1.4 | 8.6 | 6/13/60 | -- | D | |
| -2 | E. Bodkin | -- | Dug | 45 | -- | 36 | -- | Qd | 315 | Top of well cover | LS | p16.8 | 6/13/60 | -- | D | |
| 314-900-1 | M. Bradley | 1957 | Drl | r74 | r56 | r6 | r55 | Oq | 310 | -- | -- | -- | -- | -- | D | |
| -2 | C. McCubbins | -- | Dug | 13 | -- | 36 | -- | Qd | 310 | Top of well cover | .4 | 2.6 | 6/13/60 | -- | D, A | T 50 6/13/60. |
| -3 | G. Browning | -- | Dug | 20 | -- | a36 | -- | Qd | 305 | Top of well curbing | LS | p12.9 | 6/13/60 | -- | D | inadequate in dry summers. |
| 314-902-1 | Frontier Homes | -- | Drl | 42 | -- | 6 | -- | Oq? | 300 | Top of casing | LS | 2.0 | 9/14/60 | -- | Ir, A | |
| 315-826-1 | B. Ellsmore | 1950 | Drl | 43 | 34 | 6 | 34 | Oq | 410 | do. | 1.5 | 13.5 | 11/15/61 | -- | D | Cl 18.5 11/15/61. |

Table 7.--Records of selected wells in the Niagara Falls area (Continued)

| Well number | Owner | Year completed | Type of well | Depth of well (feet) | Depth of casing (feet) | Diameter (inches) | Depth to bedrock (feet) | Water-bearing material | Altitude above sea level (feet) | Measuring point: Description | Measuring point: Position | Water level: Below land surface (feet) | Water level: Date | Yield (gallons per minute) | Use | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 315-853-1 | C. Michel | 1955 | Drl | 49 | r40 | 6 | r40 | Oq | 310 | Top of casing | 0.9 | 14.0 | 11/ 8/60 | b40 | D | Aquifer is fractured zone at top of shale. |
| 315-857-1 | E. Eagle | 1959 | Drl | 88 | r41 | 6 | r40 | Oq | 305 | do. | 1.8 | 13.D | 6/15/60 | b1 | D, S | Slightly salty. |
| -2 | do. | -- | Dug | 12 | -- | a30 | -- | Qd | 305 | Top of well cover | .3 | 3.1 | 6/15/60 | -- | D, U | |
| 315-858-1 | H. Schultz | -- | Dug | r14 | -- | a40 | -- | Qd | 300 | Wooden pump base | 2.0 | 4.5 | 6/15/60 | -- | D, U | |
| -2 | J. Canfield | -- | Dug, Drl | r160 | -- | -- | -- | Qd, Oq | s307 | Top of well cover | LS | 2.2 | 6/15/60 | -- | S | |
| 315-859-1 | R. Tower | -- | Dug | 24 | -- | a36 | -- | Qlc | s301 | do. | .5 | F,3.7 | 6/14/60 | -- | D, O | Well Ni 30 in U.S.G.S. Circ. 173; U.S.G.S. observation well; pt. |
| -2 | do. | -- | Dug | 21 | -- | a48 | -- | Qlc | 300 | do. | 1.0 | 3.5 | 6/14/60 | -- | D | |
| 315-900-1 | F. McClellan | -- | Dug | 24 | -- | a36 | -- | Qd | s299 | do. | LS | 4.7 | 6/13/60 | -- | D | |
| 316-820-1 | R. Carver | 1960 | Drl | 43 | r30 | 6 | r30 | Oq | 410 | Top of casing | .5 | 11.1 | 10/24/61 | b5 | D | |
| 316-822-1 | C. Reak | -- | Dug, Drl | r72 | -- | 36, 6 | -- | Qd, Oq | 425 | Bottom of well cover | LS | 13.4 | 10/24/61 | -- | D | |
| 316-843-1 | L. Hayes | 1959 | Dug | 18 | 8 | 48 | 8 | Oq | 345 | Top of well cover | LS | 16.6 | 11/ 8/61 | -- | D | Anal. |
| -2 | D. Auman | -- | Drl | 33 | a8 | 6 | a8 | Oq | 345 | Top of casing | 1.4 | 16.5 | 11/ 8/61 | -- | D | Inadequate. |
| 316-858-1 | B. Wilson | 1957 | Dug | 7 | -- | 48 | -- | Qd | 250 | Base of well cover | LS | 2.7 | 6/15/60 | -- | D, U | |
| 316-859-1 | Niagara Frontier State Park Commission | 1961 | Drl | r81 | r51 | 8 | r52 | Qsg | 270 | Top of casing | 2.0 | 26.1 | 8/10/61 | b34 | PS | Log; bailed at 34 gpm with 40 ft dd; aquifer is gravel at top of rock. |
| 316-900-1 | R. Schears | -- | Drl | 55 | r50 | 6 | r50 | Oq | 280 | do. | .4 | p23.0 | 6/14/60 | -- | D | |
| 316-901-1 | C. Armstrong | -- | Drl | 78 | -- | 6 | -- | Oq | 275 | do. | 1.1 | 30.1 | 9/14/60 | -- | D | Adequate for two families. |
| 317-827-1 | B. Pittman | -- | Dug | 14 | -- | 30 | -- | Qls | 340 | Top of well cover | LS | 9.8 | 11/15/61 | -- | D | |
| 317-832-1 | W. Lampo | -- | Dug | 9 | -- | 36 | -- | Qti | 370 | -- | -- | Dry | 11/15/61 | -- | D | Inadequate. |
| -2 | do. | 1954 | Drl | 14 | -- | 6 | -- | Oq? | 370 | Top of casing | LS | 11.1 | 11/15/61 | -- | D | Do. |
| 318-821-1 | D. Allport | -- | Dug | 10 | 10 | 12 | -- | Qls | 330 | Top of well cover | -4.0 | 7.6 | 11/15/61 | -- | D | |
| 318-839-1 | L. Stojek | 1957 | Dug | 18 | 18 | 48 | r16 | Oq | 340 | do. | 2.2 | 12.7 | 11/15/61 | -- | D | |
| 318-841-1 | C. O'Connor | -- | Dug | 11 | -- | a36 | -- | Qd | 340 | Top of curbing | LS | 7.9 | 11/15/61 | -- | D | |
| 319-821-1 | G. Waters | 1958 | Drl | 36 | 35 | 6 | 35 | Oq | 330 | Top of casing | -5.0 | 18.0 | 11/15/61 | -- | D | Anal.; aquifer is fractured zone at top of shale. |

Table 8.--Records of selected springs in the Niagara Falls area

Spring number: See "Well-Numbering System" in text for explanation.

Altitude above sea level: s - altitude of land surface measured by surveying instruments and given to nearest foot. All others estimated from topographic maps to nearest 10 feet.

Yield: e - estimated yield. All others measured

Use: D - domestic; PS - public supply; U - unused

Remarks: Anal. - chemical analysis in this report; Cl - chloride content in parts per million; $H_2S$ - noticeable odor of hydrogen sulfide

| Spring number | Owner | Topographic situation | Source of spring | Altitude above sea level (feet) | Yield (gallons per minute) | Date of yield and temperature measurement | Temperature (°F) | Use | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| 306-903-1Sp | Niagara Frontier State Park Commission | Side of Niagara River gorge | Bedding joint at base of massive bed in Lockport Dolomite | s524 | 0.4 | 8/ 8/61 | 58.0 | U | Dry in fall of 1960. |
| 309-824-2Sp | -- | Valley floor | Sandy glacial till | 620 | 2.0 | 10/20/61 | 52.5 | U | |
| 309-902-1Sp | New York Central R.R.? | Niagara escarpment | Enlarged vertical joint at contact between DeCew Limestone Member of Williams (1919) and Gasport Limestone Member of Lockport Dolomite. | s562 | 12.0<br>12.0 | 8/ 4/60<br>8/ 7/61 | 54.0<br>55.0 | U | Anal. |
| -2Sp | State of New York | Side of Niagara River gorge | Seepage from enlarged vertical joints in two caves aligned along contact between DeCew and Gasport Members of Lockport Dolomite | s536 | e15 | 9/ 9/60 | 61.0 | U | Contaminated with detergents, strong odor, much higher yield in spring of year. |
| -3Sp | do. | Cliff; gorge of Niagara River | Seepage from four enlarged vertical joints in cave at contact between DeCew and Gasport Members of Lockport Dolomite | s536 | 15-20 | 9/ 9/60 | 58.5 | U | Do. |
| -5Sp | Power Authority of the State of New York | Hillside; gentle slope | Concealed; probably contact between Whirlpool Sandstone and Queenston Shale | s323 | 13.0<br>2.0 | 8/ 8/61<br>9/14/61 | 53.0<br>49.5 | U | $H_2S$. |
| 310-858-1Sp | -- | Hillside; Niagara escarpment | Concealed; probably enlarged joints at contact between DeCew and Gasport Members of Lockport Dolomite | 610 | e2 | 8/ 4/60 | 49.2 | U | Anal. |
| -4Sp | E. Green | Steep hillside; Niagara escarpment | Intersection of bedding joints and vertical joints in Irondequoit Limestone | s521 | e30<br>72 | 6/29/61<br>8/ 7/61 | --<br>58.0 | U | High yield on 8/7/61 because of rain on previous day. |
| -5Sp | -- | do. | do. | 520 | e20 | 8/ 7/61 | 56.0 | U | |
| 310-859-6Sp | G. Patterson | Cliff; Niagara escarpment | Enlarged bedding joints and vertical joints at base of Gasport Member of Lockport Dolomite | 600 | e5 | 8/25/60 | 53.2 | PS | Anal.; supplies trailer court with eight families. |

Table 8.--Records of selected springs in the Niagara Falls area (Continued)

| Spring number | Owner | Topographic situation | Source of spring | Altitude above sea level (feet) | Yield (gallons per minute) | Date of yield and temperature measuremant | Temperature (°F) | Use | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| 310-900-1Sp | -- | Steep hillside; Niagara escarpment | Enlarged bedding joints and vertical joints at base of Gasport Member of Lockport Dolomite | 600 | 7<br>4.5 | 8/ 4/60<br>9/14/61 | 50.2<br>51.0 | U | Anal. |
| 310-901-1Sp | J. Daggett | Cliff; Niagara escarpment | Enlarged vertical joint at base of Gasport Member of Lockport Dolomite | s573 | 2.5<br>4.8 | 8/ 4/60<br>8/ 7/61 | 51.0<br>52.5 | U | Anal. |
| -2Sp | New York Central R.R. | Hillside; Niagara escarpment | Bedding joint at base of Irondequoit Limestone | 490 | .6 | 8/ 7/61 | 49.5 | U | |
| 310-902-2Sp | W. Blauvelt | Hillside; bluff above Niagara River | Bedding joints in Queenston Shale | 280 | e10 | 9/ 8/60 | 49.5 | U | Anal.; known as "Lewiston Spring." |
| 311-823-1Sp | -- | Hillside; bluff overlooking stream | Contact between DeCew and Gasport Members of Lockport Dolomite | 590 | e5 | 10/24/61 | 51.5 | U | |
| 311-838-1Sp | R. Levan | Hillside; Niagara escarpment | Concealed; probably contact between DeCew and Gasport Members of Lockport Dolomite | 600 | 15-20 | 8/17/61 | 53.3 | D | Anal. |
| -4Sp | W. Wislowski | Steep hillside; Niagara escarpment | Concealed; probably contact between Pleistocene sand and gravel and underlying till | 590 | 1.2 | 8/22/61 | 49.8 | U | Cl 125 8/22/61. |
| 311-846-1Sp | -- | Hillside; Niagara escarpment | Contact between Reynales Limestone and Neahga Shale of Sanford (1933) | 500 | e2 | 6/16/61 | 55.1 | U | |

Table 9.--Chemical analyses of ground water from the Niagara Falls area

Well, spring, or excavation number: See "Well-Numbering System" in text for explanation. Springs are designated by "Sp" following the number. Test holes and observation points in excavations are designated by small letters following the numbers.

Depth of well: All depths below land surface.
r - reported
all others measured

Water-bearing material:
Oq - Queenston Shale
Qd - Pleistocene deposits, undifferentiated
Qsg - Pleistocene sand and gravel
Sa - Albion Group
Sc - Clinton Group
Sl - Lockport Dolomite

Remarks: All analyses by U.S. Geological Survey, Quality of Water Branch, unless noted otherwise.
PASNY - well number assigned by Power Authority of the State of New York.

(All results in parts per million except specific conductance, pH, and color)

| Well, spring, or excavation number | Date of collection | Depth of well (feet) | Water-bearing material | Silica ($SiO_2$) | Iron (Fe) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Bicarbonate ($HCO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Dissolved solids (residue at 180°C) | Hardness (as $CaCO_3$) Calcium, magnesium | Hardness (as $CaCO_3$) Noncarbonate | Specific conductance (micromhos at 25°C) | pH | Color | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 304-851-1 | 10/20/60 | 68 | Sl | 11 | 0.07 | 520 | 164 | 437 | 9.8 | 102 | 1,840 | 658 | 1.2 | 1.7 | 3,990 | 1,970 | 1,890 | 4,740 | 7.7 | 2 | Well may obtain some water from overlying rocks of the Salina Group. |
| 304-901-2 | -- | r148 | Sl | 5 | .1 | -- | 12 | --- | -- | 122 | 87 | 3 | -- | --- | 306 | 120 | ---- | ---- | -- | -- | Analysed by E. I. du Pont de Nemours & Co. Cu < 0.03 |
| -6 | 6/18/51 | r125 | Sl | 1.4 | .05 | 66 | 10 | 18 | 4.0 | 121 | 94 | 36 | .4 | .5 | 299 | 206 | ---- | 488 | 7.4 | 10 | Cu 0.0, Zn 0.1 |
| 305-900-1 | 12/ 4/58 | 139 | Sl | 10 | .12 | 736 | 122 | a/ 550 | -- | 272 | 1,600 | 1,160 | -- | --- | 4,570 | 2,390 | ---- | ---- | 7.3 | -- | Data obtained from Layne-New York Co., Inc. |
| -3 | 2/27/40 | r100 | Sl | -- | 16? | 788 | 50 | --- | -- | 271 | 1,140 | 1,000 | -- | --- | 3,230 | 2,180 | ---- | ---- | 7.0 | -- | Analyst, W. H. Betz, Philadelphia, Pa. |
| 307-901-1 | 8/10/60 | 29 | Sl | -- | -- | -- | -- | --- | -- | --- | --- | 72 | -- | --- | ---- | ---- | ---- | 1,310 | -- | -- | |
| -2 | 8/10/60 | 29 | Sl | -- | -- | -- | -- | --- | -- | --- | --- | 57 | -- | --- | ---- | ---- | ---- | 1,220 | -- | -- | |
| 307-903-1 | 10/17/61 | 110 | Sl | -- | -- | -- | -- | --- | -- | 382 | 258 | b/ 105 | -- | --- | 922 | 659 | ---- | 1,330 | 7.2 | -- | |
| 308-850-1 | 7/21/59 | r63 | Sl | 9.9 | .29 | 316 | 65 | 30 | | 356 | 740 | 40 | .9 | .9 | 1,460 | 1,060 | 765 | 1,740 | 6.6 | 7 | Mn 0.11 |
| -1 | 10/10/60 | | | 9.3 | .73 | 244 | 52 | 29 | | 360 | 516 | 36 | .9 | .9 | 1,200 | 824 | 529 | 1,490 | 6.9 | 4 | Mn 0.1 |
| -2 | 7/21/59 | r61 | Sl | 9.4 | 1.2 | 248 | 68 | 43 | | 360 | 585 | 61 | .9 | .2 | 1,280 | 899 | 604 | 1,600 | 6.8 | 2 | Mn 0.17 |
| -2 | 10/10/60 | | | 8.8 | .14 | 120 | 44 | 78 | | 340 | 208 | 106 | .6 | 4.0 | 831 | 481 | 202 | 1,260 | 7.2 | 2 | Mn 0.0 |
| 308-859-4 | 8/23/60 | 100 | Sl | -- | -- | -- | -- | --- | -- | --- | --- | 18 | -- | --- | ---- | ---- | ---- | 758 | -- | -- | PASNY OW 118 |
| 308-900-16 | 4/13/62 | 47 | Sl | -- | -- | -- | -- | --- | -- | 318 | 1,120 | 65 | -- | --- | 2,200 | 1,410 | 1,200 | 2,160 | 6.9 | -- | PASNY OW 182 |
| -16 | 5/14/62 | | | -- | -- | -- | -- | --- | -- | 320 | 1,070 | 58 | -- | --- | 2,130 | 1,380 | 1,120 | 2,200 | 7.1 | -- | |
| -16 | 7/ 6/62 | | | -- | -- | -- | -- | --- | -- | 320 | 1,060 | 54 | -- | --- | 2,090 | 1,500 | 1,240 | 2,230 | 7.1 | -- | |
| -16 | 11/14/62 | | | -- | -- | -- | -- | --- | -- | 364 | 1,030 | 50 | -- | --- | 2,010 | 1,500 | 1,200 | 2,180 | 7.0 | -- | |
| -19 | 5/14/62 | 50 | Sl | -- | -- | -- | -- | --- | -- | 362 | 271 | 74 | -- | --- | 928 | 570 | 270 | 1,130 | 7.1 | -- | PASNY OW 204 |
| -19 | 7/ 9/62 | | | -- | -- | -- | -- | --- | -- | 364 | 315 | 71 | -- | --- | 864 | 670 | 371 | 1,200 | 7.0 | -- | |
| -20 | 5/14/62 | r55 | Sl | -- | -- | -- | -- | --- | -- | 314 | 317 | 80 | -- | --- | 993 | 592 | 284 | 1,140 | 7.2 | -- | PASNY OW 190 |
| -20 | 7/ 9/62 | | | -- | -- | -- | -- | --- | -- | 324 | 315 | 80 | -- | --- | 901 | 660 | 394 | 1,220 | 7.2 | -- | |
| 308-902-1 | 8/25/60 | 6 | Qd | -- | -- | -- | -- | --- | -- | --- | --- | 61 | -- | --- | ---- | ---- | ---- | 949 | -- | -- | |

a/ Calculated.

b/ Field determination by writer.

Table 9.--Chemical analyses of ground water from the Niagara Falls area (Continued)

| Well, spring, or excavation number | Date of collection | Depth of well (feet) | Water-bearing material | Silica ($SiO_2$) | Iron (Fe) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Bicarbonate ($HCO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Dissolved solids (residue at 180°C) | Hardness (as $CaCO_3$) Calcium, magnesium | Hardness (as $CaCO_3$) Noncarbonate | Specific conductance (micromhos at 25°C) | pH | Color | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 309-850-1 | 2/ 4/60 | r40 | Sl | 9.5 | 0.15 | 72 | 34 | 3.9 | | 283 | 78 | 10 | 0.3 | 0.4 | 357 | 320 | 88 | 615 | 7.3 | 4 | |
| -2 | 2/ 4/60 | r43 | Sl | 12 | .09 | 109 | 36 | 20 | | 310 | 132 | 42 | .3 | 14 | 545 | 420 | 166 | 850 | 7.2 | 2 | |
| 309-856-5 | 9/13/60 | r22 | Sl | -- | -- | -- | -- | --- | -- | --- | --- | 32 | -- | --- | ---- | ---- | ---- | 846 | -- | -- | |
| 309-858-1 | 9/13/60 | 29 | Sl | -- | -- | -- | -- | --- | -- | --- | --- | 21 | -- | --- | ---- | ---- | ---- | 805 | -- | -- | |
| -3 | 4/13/62 | 60 | Sl | -- | -- | -- | -- | --- | -- | 200 | 318 | 91 | -- | --- | 896 | 535 | 371 | 1,150 | 7.6 | -- | PASNY OW 206 |
| -3 | 5/14/62 | | | -- | -- | -- | -- | --- | -- | 188 | 305 | 104 | -- | --- | 875 | 528 | 374 | 1,160 | 7.3 | -- | |
| -3 | 7/ 6/62 | | | -- | -- | -- | -- | --- | -- | 237 | 315 | 120 | -- | --- | 883 | 570 | 376 | 1,270 | 7.3 | -- | |
| -3 | 11/14/62 | | | -- | -- | -- | -- | --- | -- | 320 | 262 | 120 | -- | --- | 805 | 578 | 316 | 1,240 | 7.0 | -- | |
| -4 | 4/13/62 | 15 | Sl | -- | -- | -- | -- | --- | -- | 162 | 277 | 48 | -- | --- | 687 | 443 | 310 | 906 | 7.4 | -- | PASNY OW 205 |
| -4 | 5/14/62 | | | -- | -- | -- | -- | --- | -- | 141 | 250 | 41 | -- | --- | 640 | 387 | 271 | 811 | 7.5 | -- | |
| -4 | 7/ 6/62 | | | -- | -- | -- | -- | --- | -- | 154 | 210 | 40 | -- | --- | 562 | 380 | 254 | 810 | 7.7 | -- | |
| -4 | 11/14/62 | | | -- | -- | -- | -- | --- | -- | 228 | 156 | 48 | -- | --- | 457 | 350 | 163 | 713 | 7.2 | -- | |
| 309-859-1 | 5/14/62 | 70 | Sl | -- | -- | -- | -- | --- | -- | 134 | 1,400 | 1,530 | -- | --- | 5,000 | 1,990 | 1,800 | 6,390 | 6.8 | -- | PASNY OW 107 |
| -1 | 11/14/62 | | | -- | -- | -- | -- | --- | -- | 38 | 1,540 | 123,000 | -- | --- | 198,000 | 29,200 | 29,200 | 137,000 | 5.9 | -- | Density 1.154 g/ml, Cl may include bromide and iodide. Collected at level of water-bearing zone 1. |
| -1 | 11/14/62 | | | -- | -- | -- | -- | --- | -- | 120 | 1,460 | 1,480 | -- | --- | 4,590 | 2,230 | 2,130 | 6,240 | 6.5 | -- | Collected at level of water-bearing zone 3. |
| -2 | 10/11/60 | 70 | Sl | -- | -- | -- | -- | --- | -- | 303 | 1,490 | b/ 1,400 | -- | --- | ---- | 2,660 | ---- | ---- | 6.7 | -- | PASNY OW 108 |
| -2 | 11/14/62 | | | -- | -- | -- | -- | --- | -- | 224 | 1,690 | 11,200 | -- | --- | 21,000 | 8,400 | 8,210 | 27,400 | 7.3 | -- | Density 1.014 g/ml, Cl may include bromide and iodide. Collected at level of water-bearing zone 1. |
| -3 | 5/14/62 | 61 | Sl | -- | -- | -- | -- | --- | -- | 460 | 145 | 32 | -- | --- | 632 | 449 | 72 | 910 | 7.1 | -- | PASNY OW 109 |
| -3 | 11/14/62 | | | -- | -- | -- | -- | --- | -- | 428 | 932 | 700 | -- | --- | 2,650 | 1,440 | 1,090 | 3,630 | 7.0 | -- | Collected at level of water-bearing zone 1. |
| 309-900-9 | 4/13/62 | 59 | Sl | -- | -- | -- | -- | --- | -- | 365 | 1,300 | 590 | -- | --- | 3,490 | 1,860 | 1,560 | 4,010 | 7.3 | -- | PASNY OW 196 |
| -9 | 5/14/62 | | | -- | -- | -- | -- | --- | -- | 396 | 1,380 | 790 | -- | --- | 3,900 | 2,100 | 1,770 | 4,590 | 6.8 | -- | |
| -9 | 7/ 9/62 | | | -- | -- | -- | -- | --- | -- | 409 | 1,260 | 670 | -- | --- | 3,560 | 1,990 | 1,650 | 4,420 | 6.8 | -- | Slight $H_2S$ |
| -9 | 11/14/62 | | | -- | -- | -- | -- | --- | -- | 424 | 1,260 | 148 | -- | --- | 2,360 | 1,620 | 1,270 | 2,660 | 6.8 | -- | |
| 309-901-7 | 5/14/62 | 111 | Sl | -- | -- | -- | -- | --- | -- | 304 | 75 | 1,490 | -- | --- | 3,670 | 1,450 | 1,200 | 5,060 | 7.1 | -- | PASNY OW 123 |
| -7 | 11/14/62 | | | -- | -- | -- | -- | --- | -- | 320 | 868 | 1,170 | -- | --- | 3,460 | 1,840 | 1,580 | 4,980 | 6.9 | -- | Collected at level of water-bearing zone 1. |
| 309-902-1Sp | 8/ 4/60 | --- | Sl | -- | -- | -- | -- | --- | -- | 314 | 101 | 72 | -- | --- | 586 | 450 | 192 | 917 | 8.0 | -- | |
| 310-853-1 | 10/28/60 | 57 | Sc, Sa | -- | -- | -- | -- | --- | -- | 168 | 768 | b/ 1,500 | -- | --- | ---- | 1,750 | ---- | ---- | 7.0 | -- | |
| 310-854-4 | 10/28/60 | 61 | Sa | -- | -- | -- | -- | --- | -- | 159 | 794 | b/ 4,450 | -- | --- | ---- | 2,790 | ---- | ---- | 6.5 | -- | |
| 310-858-1Sp | 8/ 4/60 | --- | Sl | -- | -- | -- | -- | --- | -- | 316 | 91 | 25 | -- | --- | 428 | 378 | 119 | 703 | 7.6 | -- | |
| 310-859-1 | 8/23/60 | 113 | Sc | -- | -- | -- | -- | --- | -- | --- | --- | 54 | -- | --- | ---- | ---- | ---- | 823 | -- | -- | |
| -3 | 8/25/60 | 62 | Oq | -- | -- | -- | -- | --- | -- | 239 | 580 | 470 | -- | --- | 1,860 | 366 | 170 | 2,900 | 7.3 | -- | |

b/ Field determination by writer.

Table 9.--Chemical analyses of ground water from the Niagara Falls area (Continued)

| Well, spring, or excavation number | Date of collection | Depth of well (feet) | Water-bearing material | Silica ($SiO_2$) | Iron (Fe) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Bicarbonate ($HCO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Dissolved solids (residue at 180°C) | Hardness (as $CaCO_3$) | | Specific conductance (micromhos at 25°C) | pH | Color | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | Calcium, magnesium | Noncarbonate | | | | |
| 310-859-4 | 8/25/60 | 23 | Qd | -- | -- | -- | -- | --- | -- | --- | --- | 332 | -- | --- | ---- | ---- | ---- | 2,240 | -- | -- | |
| -5 | 8/25/60 | r114 | Oq | -- | -- | -- | -- | --- | -- | 226 | 1,010 | 1,460 | -- | --- | 4,430 | 928 | 743 | 6,800 | 7.8 | -- | |
| -6Sp | 8/25/60 | --- | Sl | -- | -- | -- | -- | --- | -- | 124 | 244 | 250 | -- | --- | 998 | 470 | 368 | 1,460 | 8.0 | -- | |
| -6Sp | 4/13/62 | | | -- | -- | -- | -- | --- | -- | 268 | 242 | 140 | -- | 5.2 | 838 | 529 | 309 | 1,180 | 7.5 | -- | |
| 310-859-7 | 9/ 7/60 | 137 | Sa | -- | -- | -- | -- | --- | -- | 298 | 344 | 820 | -- | --- | 2,790 | 1,260 | 1,020 | 3,720 | 7.1 | -- | |
| 310-900-1Sp | 8/ 4/60 | --- | Sl | -- | -- | -- | -- | --- | -- | 402 | 141 | 45 | -- | --- | 692 | 539 | 209 | 984 | 7.2 | -- | |
| 310-901-1Sp | 8/ 4/60 | --- | Sl | -- | -- | -- | -- | --- | -- | 312 | 129 | 32 | -- | --- | 574 | 449 | 193 | 811 | 7.1 | -- | |
| 310-902-1 | 9/ 8/60 | r62 | Oq | -- | -- | -- | -- | --- | -- | 350 | 157 | 295 | -- | --- | 1,210 | 755 | 467 | 1,690 | 7.1 | -- | |
| -2Sp | 9/ 8/60 | --- | Oq | -- | -- | -- | -- | --- | -- | 372 | 108 | 175 | -- | --- | 887 | 590 | 285 | 1,310 | 7.5 | -- | |
| 311-822-1 | 9/28/61 | 34 | Sl | -- | -- | -- | -- | --- | -- | 277 | 62 | ---- | -- | --- | 376 | 337 | ---- | 607 | 7.4 | -- | |
| 311-830-2 | 9/22/61 | 16 | Sl | -- | -- | -- | -- | --- | -- | 312 | 150 | b/ 21 | -- | --- | 564 | 449 | ---- | 801 | 7.2 | -- | |
| 311-835-1 and -2 | 8/22/61 | 17 | Qsg | -- | -- | -- | -- | --- | -- | 284 | 93 | b/ 26 | -- | --- | 496 | 380 | ---- | 727 | 7.3 | -- | Sample is composite of water from both wells. |
| 311-838-1Sp | 8/17/61 | --- | Sl? | -- | -- | -- | -- | --- | -- | 296 | 117 | b/ 65 | -- | --- | 602 | 450 | ---- | 912 | 7.1 | -- | |
| -2 | 8/17/61 | 24 | Qsg | -- | -- | -- | -- | --- | -- | 396 | 242 | b/ 65 | -- | --- | 1,040 | 686 | ---- | 1,450 | 7.2 | -- | |
| 311-855-2 | 10/28/60 | 81 | Oq | -- | -- | -- | -- | --- | -- | 146 | 514 | b/3,150 | -- | --- | ---- | 1,400 | ---- | ---- | 6.8 | -- | |
| 311-859-4 | 6/19/48 | r65 | Oq | 3.0 | 1.0 | 521 | 65 | 2,340 | 41 | 9 | 3,620 | 2,100 | 1.0 | 12 | 8,920 | 1,570 | ---- | 11,900 | 5.7 | 3 | Ni 8; Al 1.0, Cu 0, Zn 4.2, $PO_4$ 0 |
| 312-853-1 | 11/ 1/60 | 41 | Oq | -- | -- | -- | -- | --- | -- | 238 | 1,780 | b/ 750 | -- | --- | ---- | 1,910 | ---- | ---- | 7.1 | -- | |
| -3 | 11/ 1/60 | 77 | Oq | -- | -- | -- | -- | --- | -- | 161 | 298 | b/1,050 | -- | --- | ---- | 765 | ---- | ---- | 7.4 | -- | |
| 312-859-1 | 6/18/48 | 15 | Qd | 12 | .98 | 132 | 58 | 69 | 41 | 414 | 196 | 105 | 1.7 | 23 | 878 | 568 | ---- | 1,380 | 8.2 | 9 | Ni 5; $CO_3$ 22, Al 0.2, Zn 0.8 |
| 313-859-1 | 6/18/48 | 48 | Qd, Oq | 11 | .79 | 124 | 145 | 106 | 4.2 | 396 | 416 | 140 | .2 | 150 | 1,390 | 906 | ---- | 1,990 | 8.2 | 2 | Ni 22; $CO_3$ 23, Al 0.6, Cu 0, Zn 0, $PO_4$ 0.1 |
| 316-843-1 | 11/ 8/61 | 18 | Oq | -- | -- | -- | -- | --- | -- | 363 | 60 | b/ 90 | -- | --- | 533 | 331 | ---- | 927 | 7.4 | -- | |
| 319-821-1 | 11/15/61 | 36 | Oq | -- | -- | -- | -- | --- | -- | 175 | 28 | b/ 235 | -- | --- | 605 | 219 | ---- | 1,070 | 7.4 | -- | |
| Samples collected in the conduit excavations of the Niagara Power Project: | | | | | | | | | | | | | | | | | | | | | |
| 304-901-a | 7/19/60 | --- | Sl | -- | -- | -- | -- | --- | -- | 119 | 532 | 59 | -- | --- | 1,090 | 746 | 649 | 1,330 | 7.1 | -- | |
| -b | 7/19/60 | --- | Sl | -- | -- | -- | -- | --- | -- | 372 | 1,320 | 320 | -- | --- | 2,950 | 1,880 | 1,570 | 3,470 | 6.9 | -- | Water-bearing zone 6 |
| 308-901-e | 10/26/60 | --- | Sl | 7.7 | .05 | 708 | 105 | 556 | 27 | 326 | 1,510 | 1,140 | .6 | 1.8 | 4,520 | 2,200 | 1,930 | 5,880 | 7.2 | 6 | Water-bearing zone 1 (Lockport-Rochester contact) |
| 308-902-a(1) | 7/26/60 | --- | Sl | -- | -- | -- | -- | --- | -- | 302 | 476 | 900 | -- | --- | 2,780 | 1,010 | 762 | 4,290 | 7.4 | -- | Water-bearing zone 2 |
| -a(2) | 7/26/60 | | | -- | -- | -- | -- | --- | -- | 392 | 460 | 550 | -- | --- | 2,230 | 1,120 | 799 | 3,160 | 7.2 | -- | Water-bearing zone 1 |
| Samples collected from test holes at the Robert Moses Generating Plant, Niagara Power Project: | | | | | | | | | | | | | | | | | | | | | |
| 308-902-b(1) | 8/25/60 | --- | Oq | -- | -- | -- | -- | --- | -- | 46 | 843 | 5,110 | -- | --- | 11,200 | 3,020 | 2,980 | 16,000 | 7.4 | -- | |
| -b(2) | 9/26/60 | | | -- | -- | -- | -- | --- | -- | 101 | 1,630 | b/6,300 | -- | --- | ---- | 4,840 | ---- | ---- | 6.5 | -- | |
| -c | 6/ 6/61 | --- | Sc | -- | -- | -- | -- | --- | -- | 1,440 | 18 | ---- | -- | --- | 4,880 | 1,380 | ---- | 7,720 | 6.6 | -- | |

b/ Field determination by writer.

REPORTS DEALING WITH GROUND-WATER CONDITIONS IN NEW YORK

Published by the New York Water Resources Commission and prepared in cooperation with the U.S. Geological Survey

An asterisk (*) indicates that the report is out of print, but such reports are available for consultation in certain libraries.

BULLETINS:

*GW- 1 WITHDRAWAL OF GROUND WATER ON LONG ISLAND, N. Y.
D. G. Thompson and R. M. Leggette (1936)

*GW- 2 ENGINEERING REPORT ON THE WATER SUPPLIES OF LONG ISLAND.
Russell Suter (1937)

*GW- 3 RECORD OF WELLS IN KINGS COUNTY, N. Y.
R. M. Leggette and others (1937)

*GW- 4 RECORD OF WELLS IN SUFFOLK COUNTY, N. Y.
R. M. Leggette and others (1938)

*GW- 5 RECORD OF WELLS IN NASSAU COUNTY, N. Y.
R. M. Leggette and others (1938)

*GW- 6 RECORD OF WELLS IN QUEENS COUNTY, N. Y.
R. M. Leggette and others (1938)

*GW- 7 REPORT ON THE GEOLOGY AND HYDROLOGY OF KINGS AND QUEENS COUNTIES, LONG ISLAND.
Homer Sanford (1938)

GW- 8 RECORD OF WELLS IN KINGS COUNTY, N. Y., SUPPLEMENT 1.
R. M. Leggette and M. L. Brashears, Jr. (1944)

GW- 9 RECORD OF WELLS IN SUFFOLK COUNTY, N. Y., SUPPLEMENT 1.
C. M. Roberts and M. L. Brashears, Jr. (1945)

GW-10 RECORD OF WELLS IN NASSAU COUNTY, N. Y., SUPPLEMENT 1.
C. M. Roberts and M. L. Brashears, Jr. (1946)

*GW-11 RECORD OF WELLS IN QUEENS COUNTY, N. Y., SUPPLEMENT 1.
C. M. Roberts and Marion C. Jaster (1947)

*GW-12 THE WATER TABLE IN THE WESTERN AND CENTRAL PARTS OF LONG ISLAND, N. Y.
C. E. Jacob (1945)

*GW-13 THE CONFIGURATION OF THE ROCK FLOOR IN WESTERN LONG ISLAND, N. Y.
Wallace de Laguna and M. L. Brashears, Jr. (1948)

GW-14 CORRELATION OF GROUND-WATER LEVELS AND PRECIPITATION ON LONG ISLAND, N. Y.
C. E. Jacob (1945)

*GW-15 PROGRESS REPORT ON GROUND-WATER RESOURCES OF THE SOUTHWESTERN PART OF BROOME COUNTY, N. Y.
R. H. Brown and J. G. Ferris (1946)

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REPORTS DEALING WITH GROUND-WATER CONDITIONS IN NEW YORK (Continued)

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